Jansky
VOL II
EMC ENCYCLOPEDIA
DWCI

MULTI-VOLUME EMC ENCYCLOPEDIA SERIES

VOLUME II

SPECTRUM MANAGEMENT TECHNIQUES

Donald M. Jansky

Publisher:
Don White Consultants, Inc.

Spectrum Management Information Center

MULTI-VOLUME EMC ENCYCLOPEDIA SERIES

VOLUME II

SPECTRUM MANAGEMENT TECHNIQUES

Donald M. Jansky

Publisher:
Don White Consultants, Inc.

MULTI-VOLUME EMC ENCYCLOPEDIA SERIES

VOLUME II

SPECTRUM MANAGEMENT TECHNIQUES

By

Donald M. Jansky
Assistant Director
Office of Telecommunications Policy
Executive Office of the President

1st Edition

DON WHITE CONSULTANTS, INC.
14800 Springfield Road
Germantown, Maryland 20767
Phone: 301-948-0028
TLX: DWCI-GTWN 89-2766

Library of Congress Catalog Card Number 76-52508

Printed in the United States of America

Editor-in-Chief: Donald R.J. White
Editorial Director: Robert D. Goldblum
Reviewing Editor: Charles F.W. Anderson
Publisher: Don White Consultants, Inc.

FOREWORD

It is with great pleasure on behalf of Don White Consultants, Inc. (DWCI) that I release this volume, Vol. II, Spectrum Management Techniques. This is the first of our new 42-volume encyclopedia on EMC and related topics. It represents a milestone for us at DWCI since the plan calls for producing these volumes at the rate of about six per year through the year 1982.

Each of the volumes will be prepared by recognized experts in the field. Nine volumes are now in preparation. DWCI's role is to provide the technical guidance, editing, logistics, financing, publishing and promotion. These books will provide a major contribution to the EMC and related technologies for years to come.

Regarding this volume on Spectrum Management Techniques, it fills an existing void. Thus, the reader concerned with spectrum engineering and management should find the answers to many questions. The author, Don Jansky, of the Office of the President of the United States, Office of Telecommunications Policy, invites your comments. Similarly, DWCI welcomes correspondence from the many readers on their thoughts about this book.

GERMANTOWN, MARYLAND
MAY 1977

DONALD R. J. WHITE

ACKNOWLEDGEMENT

Acknowledgements are due those who either directly or indirectly contributed to the production of this text. First, a principle acknowledgement is due the present and former Spectrum Management staff of the Office of Telecommunications Policy, and in particular Mr. Will Dean, Jr., the Assistant Director of OTP for Frequency Management for 1968-1975. It was and is this staff which has been responsible for the development and implementation of many of the methods described in this book. Others on the staff who have made a significant contribution in this regard, include: Mr. Lyman Hailey, Mr. Leo Buss, Mr. Edward Probst, and Capt. Robert L. Raish (Ret).

Secondly, a great appreciation is due my family for having the patience to see me through this effort. Finally, special mention should be made to those who helped prepare this document. These include Karen Byers and Arlene Roposh.

OTHER BOOKS PUBLISHED BY DWCI

(1) Electrical Filters-Synthesis, Design & Applications; published 1963, by *White Electromagnetics, Inc.* Reprinted December 1970. Fourth printing September 1976 by *Don White Consultants, Inc.*

(2) A Handbook on Methods & Procedures for Automating RFI/EMI; published 1966 by *White Electromagnetics, Inc.*

(3) Volume 1, Electrical Noise & Electromagnetic Interference Specifications; published 1971, by *Don White Consultants, Inc.*

(4) Volume 2, Electromagnetic Interference Test Methods & Procedures; published 1974, by *Don White Consultants, Inc.*

(5) Volume 3, Electromagnetic Interference Control Methods & Techniques; published 1973, by *Don White Consultants, Inc.*

(6) Volume 4, Electromagnetic Interference Test Instrumentation Systems; published 1971, by *Don White Consultants, Inc.*

(7) Volume 5, Electromagnetic Interference Prediction & Analysis Techniques; published 1972, by *Don White Consultants, Inc.*

(8) Volume 6, Electromagnetic Interference Specifications, Standards & Regulations; published 1975, by *Don White Consultants, Inc.*

(9) A Glossary of Acronyms, Abbreviations and Symbols; published 1971, by *Don White Consultants, Inc.*

(10) A Handbook on Electromagnetic Shielding Materials and Performance; published 1975, by *Don White Consultants, Inc.*

(11) A Handbook on Mobile Communications, published 1976, by *Don White Consultants, Inc.*

PREFACE

Telecommunication systems have been called society's nervous systems. Much of the information carried by such systems is transmitted and received through controlled electromagnetic energy conveyed on a particular frequency. During the last several decades the demand for radio frequencies to carry out a variety of information transfer services has grown exponentially. The potential for congesting the air waves has grown commenserately.

The management techniques and methods which have been developed to insure that these increasing number of radio systems are capable of performing their intended functions have grown more sophisticated. This has been particularily true during the last five to ten years.

This book is concerned with the breadth and depth of modern spectrum management techniques. These techniques have been developed and applied both domestically and internationally, and have taken on a variety of forms. Also, they are applicable in the operational, planning, and technical aspects of spectrum management. In addition, there have been a considerable number of pioneering efforts at developing and applying a new generation of analytical techniques and measuring monitoring methods to improve the effective utilization of the electromagnetic spectrum.

Finally, a book on spectrum management would not be complete without a functional description of the many organizational entities which are involved in and contribute to the management of the Radio Spectrum.

BETHESDA, MARYLAND
MAY 1977

DONALD M. JANSKY

TABLE OF CONTENTS

VOL. II SPECTRUM MANAGEMENT TECHNIQUES

LIST OF ILLUSTRATIONS

ABBREVIATIONS AND SYMBOLS

A	Authorized Bandwidth
AAG	Aeronautical Assignment Group
AFNAVSAT	Air Force Navigation Satellite
AM	Amplitude Modulation
ASR	Airport Surveillance Radars
A0	Continuous Waveform (AM)
A1	Telegraphy no Keying (AM)
A2	Telegraphy with keying (AM)
A3	Telephony (AM)
A4	Facimile (AM)
A5	Television (AM)
A9	Composite Transmission (AM)
B	Emission bandwidth
B_c	Compression bandwidth
B_d	Bandwidth of frequency deviation
B_s	Bandwidth of frequency shift
CAS	Collision Avoidance System
CB	Citizens Band
CCIR	International Radio Consultative Committee
CCITT	International Consultative Committee on Telephone and Telegraph
C-E	Communications-Electronics
COMSAT	Communications Satellite Corporation
CRT	Cathode Ray Tube
D_c	Duty cycle
D_d	Pulse Compression Ratio
DNSS	DOD Navigation Satellite System
DOD	Department of Defense
E_s	Spectrum Usage Efficiency
EMC	Electromagnetic Compatibility
ERMAC	Electromagnetic Radiation Management Advisory Council
ERP	Effective Radiated Power
ES	Earth Station
FAS	Frequency Assignment Subcommittee
F_o	Nominal Operation Frequency (Radar)
FCC	Federal Communications Commission
FM	Frequency Modulation
FMAC	Frequency Management Advisory Committee
F0	Continuous Waveform (FM)
F1	Telegraphy-no keying (FM)
F2	Telegraphy-with keying (FM)
F3	Telephony (FM)

F4	Facimile (FM)
F5	Television (FM)
F9	Composite Transmission (FM)
G	Government Frequency Allocation
GHz	Gigahertz
GMF	Government Master File
g(n)	Transmitting antenna gain (satellite)
g(δ)	Receiving antenna gain (satellite)
g(θ)	Transmitting antenna gain (ES)
λ	relative to output of receiving antenna to that of the earth station
HF	High Frequency
ICAO	International Civil Aeronautical Organization
IFRB	International Frequency Registration Board
IFL	International Frequency List
ING	International Notification Group
I/N	Interference to Noise Ratio
IRAC	Interdepartment Radio Advisory Committee
ITU	International Telecommunication Union
J	Ratio of permissable long term interference to thermal noise
K	Ratio of pulse duration to pulse rise time
k	weighting factor for K
κ	Boltzman's constant
KHz	Kilohertz
Kw	Kilowatt
L-Band	1535-1660 MHz
l_d	Down path free transmission loss
l_m	Median transmission loss
l_u	Up path free space transmission loss
M	Modulation Index
M(ρ)	Permissible interference ratio
MAG	Military Assignment Group
Mhos	Conductivity
MUF	Maximum Usable Frequency
MHz	Megahertz
N_m	Median effective noise
N_s	Surface Refractivity
NG	Non Government
NGMF	Non Government Master File
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rule Making

OR	Off Route
OT	Office of Telecommunications, Dept. of Commerce
OTP	Office of Telecommunications Policy
P	Power (transmitted received)
PCPB	President's Communications Policy Board
PFD	Power Flux Density
PODAF	Power, Density, Area, Frequency
R	Route
RCVR	Receiver
RDARA	Regional Domestic Air Route Area
RF	Radio Frequency
RR	Radio Regulation
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Management System
RVD	Revision Date
RVI	Relative Value Index
$S(t_o)$	Effective Service Sum
S	Shared, Government/Non-Government Allocation
S/N	Signal-to-Noise Ratio
SER	Agency Serial Number
SPS	Spectrum Planning Subcommittee
SRI	Stanford Research Institute
ST	Space Telecommunications
TSC	Technical Subcommittee
TV	Television
UHF	Ultra High Frequency
USC	United States Code
WARC	World Administrative Radio Conference
XMTR	Transmitter
Y	Transmission Gain

CHAPTER 1

STRUCTURE AND DEVELOPMENT OF SPECTRUM MANAGEMENT

The electromagnetic frequency spectrum is one of the primary natural resources that our modern technological world has exploited usefully. Its use and application is vital for the proper functioning of many aspects of society. Yet, like all other natural resources, it too is limited. The radio frequency spectrum corresponds to wavelengths which range from tens of kilometers to thousandths of millimeters. Due to the physical nature of electromagnetic radiation, it is not bound by the geographical parameters of nations. Consequently, from the beginning of man's use of controlled radio frequencies, there has been a need for international cooperation with regard to their employment. Indeed, this need for cooperation spawned the oldest existing international organization, the International Telecommunications Union.

The applications to which such frequencies have, and are being used, have grown exponentially during the last quarter century. This growth, combined with the scarcity of the resources, has resulted in the development of management skills for control of the electromagnetic spectrum. This book will describe current techniques used to manage the electromagnetic frequency spectrum.

Spectrum management is the application of various techniques to the control and utilization of electromagnetic energy used as a vehicle for the transfer of information. The purpose of the first chapter is to describe how the techniques of spectrum management have evolved; indicating the responsible institutions and the functions they serve. In this regard, the chapter will deal with how spectrum management began and developed, its stucture and function at national and international levels of government and the concepts of spectrum engineering.

1.1 HOW SPECTRUM MANAGEMENT BEGAN

The very basis for the requirement to manage electromagnetic frequencies derives from the first successful application of devices that could produce electromagnetic energy, and be harnessed in such a way as to permit the transfer of intelligible information through the atmosphere over considerable distances. This first occurred in the operation of the Marconi wireless system to communicate with ships at sea at the beginning of the twentieth century. The wireless telegraph was first demonstrated by Marconi in 1896, and was adopted for regular nautical use in 1899 by the British Post Office. In 1901, Marconi's wireless frequencies bridged the Atlantic Ocean. Marine applications, for purposes of safety of life, grew rapidly; and, after several futile attempts, the first international conference concerning the ordering of use of the electromagnetic spectrum was convened in Berlin in 1908. This conference dealt with only one service, ship-to-shore. The frequencies of concern were 500 and 1000 kHz, designated as common calling frequencies. The former has survived to the present day.

The earliest radio equipment employed an antenna which was shock-excited into oscillation by a spark apparatus, thereby generating a radio-frequency current whose value was determined by the resonant frequency of this antenna system. Subsequent developments produced equipment which used a shock-excited local resonating circuit coupled to the antenna. However, the state of the art for many years did not permit much divergence between the resonant frequency of the antenna and the frequency of operation. For these reasons, the frequencies designated by the Berlin Convention were primarily determined by the dimensions and configurations of the supporting masts available on ships. In those days, knowledge of propagation characteristics and signal-to-noise ratios were rudimentary, bands of emission were wide, and the selectivity of the receivers was poor.

While the technology was rudimentary, the basic principles and the fundamental techniques of spectrum management had been launched. The three most important facts derived were:

1. The demand for the spectrum was in excess of that which the existing technology and physical understanding could provide;

2. Electromagnetic energy is international in character and requires conventions for its use among nations, in order to insure its effective utilization;

3. The state of the art strongly influenced the character of the agreements for its use.

Subsequently, the maritime mobile service continued to grow in importance. Point-to-point communications services began to come into being (particularly below about 300 kHz); and antennas were required

to carry out other work above 100 kHz because of the crowding in the lower frequencies. Vacuum tubes were invented which could produce frequency oscillations at higher frequencies. Electronic circuits were conceived which would permit the transmission and reception of voice and music, leading to the development of broadcasting in the early 1920's.

Rapid growth of Radio broadcasting in the U.S. precipitated the convening of the Hoover commission in 1922. The meeting of this commission (1922-1925), laid the foundation for the management and regulation of radio as we know it today. It gave rise to the establishment of the Interdepartment Radio Advisory Committee (IRAC) in 1922; and the Federal Radio Commission in 1927, the latter being the forerunner of the Federal Communications Commission (FCC). The Hoover Commission was convened largely in response to public demand for the U.S. Federal Government to do something about the electromagnetic incompatibilities deriving from the unregulated and undisciplined introduction of radio broadcasting.

The advent of the broadcasting service created a situation which has become a characteristic of spectrum management, and which simultaneously has caused the development of its managerial techniques. For instance, the broadcasters could not have the frequencies they wanted because the maritime service was already there, (i.e., 300-500 kHz). Thus, the band 550-1500 kHz was chosen as a compromise between spectrum availability, cost of equipment and technical feasibility.

The International Radio Telegraph Conference, held in Washington, D.C. in 1927, was a watershed of the early development of the use of the electromagnetic spectrum, and the development of the principles which were to govern its use. Subsequently, there ensued a period of rapid growth in radio applications with the creation of many new radio services. This is illustrated in Table 1.1 which shows the growth of the use of radio as a function of international conferences, number of radio services, and allocated spectrum. Of particular significance is the acceleration of technical growth resulting from the many new techniques and applications of the electromagnetic spectrum developed during World War II. This growth was characterized by:

- New frequency bands being utilized in the spectrum region up to 10,000 MHz.
- New services were being developed, including more sophisticated navigational aids, VHF aeronautical and land mobile communications, and television and FM broadcasting.
- The principles of radar were developed with many new services involving radiodetermination applications coming into general use.
- Revision and expansion of the International Telecommunications Union Table of Allocations.

This explosive growth set the stage for the development of today's modern techniques of spectrum management.

Table 1.1 - Expansion of Radio Services and Radio Spectrum Allocations[7]

The allocation and use of the spectrum have been growing at an enormous rate, both internationally and nationally, particularly since World War II. The following table will give an appreciation of the expansion in the usable spectrum and increases in radio services.

Year	International Radio Conference	Number of Radio Services	Spectrum Allocated
1906	Berlin	1	500 and 1,000 kHz
1912	London		150 to 1,000 kHz
1927	Washington		10 kHz to 23 MHz
1932	Madrid	5	10 kHz to 30 MHz
1938	Cairo	7	10 to 200 MHz 1/
1947	Atlantic City	15 2/	10 kHz to 10.5 GHz 2/
1959	Geneva	23 3/	10 kHz to 40 GHz
1963	Geneva (Space)	26 4/	10 kHz to 40 GHz 4/
1967	Geneva (Maritime)	26 5/	10 kHz to 40 GHz
1971	Geneva (Space)	41 6/	10 kHz to 275 GHz

Note: 1/ European Region. On the American Continent, the Table provided for allocation up to 300 MHz for future research and experiment in the amateur, broadcasting (television), fixed and mobile services.

2/ The U.S had a military allocation plan up to 30,000,000 kHz during WW II. Aeronautical and mobile services categories increased, and radiolocation, radio-navigation and standard frequency services established.

3/ Radio astronomy, radio determination and space services established, and specific provision for radar made within the radiolocation service.

4/ The U.S. allocations extended to 40 GHz, with an allocation at 88 GHz to 90 GHz to radio astronomy, and operations as high as 35 GHz, and experiments to more than 300 GHz. Communication, meteorological and radio navigation-satellite services established.

5/ Oceanographic frequencies provided.

6/ Increase reflects a large number of new satellite services.

7/ The comprehensive character of the ITU Regulations can be seen in the Table of Contents for that document which is included as Appendix 1.

1.2 DEVELOPMENT OF SPECTRUM MANAGEMENT

The Atlantic City Radio Conference of 1947 provided the basis from which today's international regulations were derived. These regulations:

1. Revised the frequency allocation table to provide *exclusive* bands for the five basic types of services - fixed, mobile, broadcasting, amateur and radiolocation (radar);

2. changed the amount of spectrum space allocated to each of these services;

3. established procedures for the preparation of a new international frequency list on the basis of sound engineering principles;

4. adopted the concept of an International Frequency Registration Board (IFRB) to register frequencies world-wide, on a technical basis.

1.2.1 Domestic Spectrum Management

The domestic basis for the development of spectrum management had been established in October, 1940, when there was consummation of an agreement between the IRAC and the FCC which stated that: "The Interdepartment Radio Advisory Committee will cooperate with Federal Communications Commission in giving notices of all proposed actions which would tend to cause interference to non-Government station operators, and the Federal Communications Commission will cooperate with the Interdepartment Radio Advisory Committee in giving notice of all proposed actions which would tend to cause interference to Government station operation. Such notification will be given in time for the other agency to comment prior to final action. Final action by either agency will not however, require approval by the other agency. The two agencies will maintain up-to-date lists of their respective authorized transmitting assignments".[3]

This agreement formalized the basic dichotomy of Spectrum Management within the U.S., i.e., there is one manager for the non-Government spectrum, and a second manager for the Government spectrum. The legal basis for this dichotomy actually derives from the Communications Act of 1934, which delegates to the President the responsibility for managing the electromagnetic spectrum as utilized by Federal Government agencies and departments and gives to the FCC the responsibility for managing the spectrum in the private sector.

Initially, the development of radio spectrum use took place on the basis of exclusivity, i.e., a particular government agency and/or

service used a particular set of frequencies for its own purposes. However, pressures for change began to make themselves felt in the 1950's. These pressures were precipitated particularly by the growth of television. The problems resulting from the manifestation of the pent-up demands for spectrum made possible by the technological developments of World War II caused the establishment of the President's Communications Policy Board (PCPB). In March 1951, it reached the following conclusions:

1. Pressure on the radio frequency spectrum is steadily increasing as a result of the greater use of radio communication.

2. The means on which we have relied in the past for management of the spectrum are no longer adequate to resolve, in the best national interest, the problems produced by this increasing pressure. The crucial difficulty growing out of the search for suitable space for television broadcasting in itself emphasizes this inadequacy.

3. Measured in terms of spectrum space rather than in number of discreet frequency channels, the Federal Government's share of the spectrum, though not so great as is commonly believed, is nevertheless large. While we do not know that it is out of proportion to the Government's responsibilities, it must have the most adequate justification and careful management if the greatest benefit is to be obtained from it.

4. There is a need for a continuing determination of the changing requests of the Federal Government users, both among themselves and in relation to the requests of the users.

5. The recent rapid growth of the telecommunications, combined with the needs of the current national emergency, makes the resolution of these problems a matter of great urgency.

6. The resolution of these problems can be secured only through adequate energetic management, which demands that the Government organize itself to take a comprehensive view of the telecommunications field.

These conclusions lead to the following basic spectrum policy statements:

Radio Frequencies

1. The United States considers that a basic guide to follow in the normal assignment of radio frequencies for transmission purposes is the avoidance of harmful interference.

2. Long-range radio frequencies, for other than overseas circuits, normally shall be used only when other forms of communication, notably wire communication, are not adequate.

3. Priorities in the normal peacetime assignment of radio frequencies shall be as follows, in the order named:

(a) Frequencies used predominantly, primarily and directly for national security and defense; which means that such frequencies are used for purposes which are vital to the safety of the nation.

(b) Frequencies used primarily, predominantly and directly to safeguard life and property in conditions of distress.

(c) Frequencies used in services that have no other adequate means of rapid communications when such communication is considered to be necessary or desirable in the national interest.

(d) Frequencies used for all other purpsoes, the assignment of which must be judged upon the merits of individual need.

Radio Spectrum Utilization

1. In view of the limitations of the usable radio spectrum, and to insure the best possible return from the use thereof; it is in the best interests of the United States, in time of peace, to require all of its users to:

(a) Justify, in a satisfactory and equitable manner, any, except an emergency, request for radio frequencies prior to the assignment of such frequencies;

(b) Confirm periodically, in terms of predetermined standards, that the use of a frequency since its latest assignment, justified the assignment;

(c) Submit evidence to indicate whether the continued assignment of a frequency is necessary.

It is in the best interest of the United States, in consideration of (a), (b), and (c) heretofore (among other considerations) to decide by high-level impartial determination, the disposition of any frequency or frequencies not assigned or re-assigned to a claimant user.

2. Common standards of performance and efficiency of radio spectrum utilization are developed and applied to each type of radio operation. All users of the radio spectrum are required to adhere to these standards. Some examples of specific recommendations, technical comments, standards, etc., applicable to specific services, are given below:

Fixed Service

1. Frequency-conserving techniques are applied whenever practicable in radio operations and particularly in the operation of point-to-point radio circuits. These techniques include such developments as single-sideband operation and frequency-shift keying.

Aeronautical

1. Public correspondence is not to be transmitted on frequencies exclusively allocated to the aeronautical mobile service.

2. The United States supports a system of radio communication between aircraft and the stations of the Maritime Mobile Service; which provides a means for the exchange of public correspondence between aircraft in flight and the general public on a worldwide basis, and enhances safety.

Maritime

1. Use of the distress frequency of 500 kHz, as prescribed by the current International Radio Regulations, shall continue to be the means primarily employed to summon assistance, or to safeguard life and property on the high seas.

Amateur

1. The Amateur Service is fostered and encouraged because the immediate availability, to all world areas, of the Amateur Services' frequencies and the amateurs who utilize them is vital during times of emergency, whether such emergency be of a localized nature or national in scope.

2. The United States considers its own Amateur Service to be vitally necessary to the national defense and security because it provides a pool of personnel trained in the techniques of telecommunications, including skilled operators".[8]

Subsequent to 1951, the federal government's spectrum management function was maintained variously by the following: (a) a Telecommunications Advisor to the President, (b) the Director of the Office of Defense Mobilization, (c) the Office of Emergency Planning (preparedness), (d) the Office of Telecommunications Management, and finally, (e) the Office of Telecommunications Policy. It was not until the establishing of this last office that the federal spectrum management function was able to begin the implementation of the PCPB's policy recommendations.

In the meantime, the use of radio had grown phenomenally. This growth is manifested in Fig. 1.1 and Table 1.2 by the kinds and types

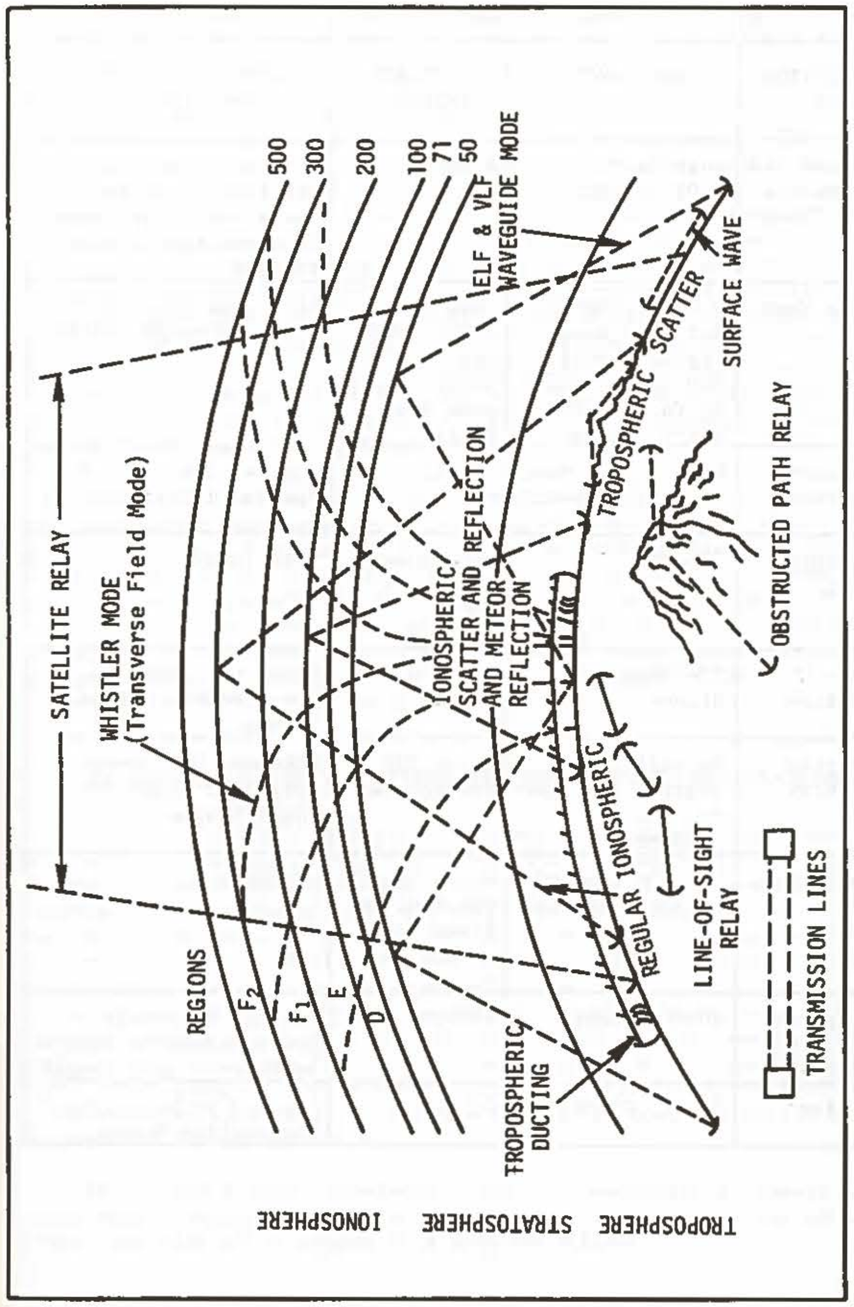


Figure 1.1 - Telecommunication Propagation Modes.

Table 1.2 - Mode of Communication by Frequency

PROPAGATION MODE	FREQUENCY	DISTANCE (MILES)	APPLICABLE R-F BANDWIDTH
Extra Low and Very Low Frequency "Waveguide"	Most Useful 0.01-0.03MHz	Global	Approx. 100Hz max limited by: Noise radiation, Efficiency, Spectrum space, distortion
Surface Wave	0.010-0.300MHz for Long Range (up to approx. 500 mi. or more). Up to 3MHz for short ranges	Less than 1200 (Greatest over sea water, least over poor soil)	Less than about 250Hz for long range systems
Ionispheric Reflection	0.03-80MHz, Most useful: 0.08-0.2: 2-30	Global	Approx. 20kHz for H.F. Apporx. 250Hz for L.F.
Ionospheric Scatter	30-60MHz	Less than 1400 most useful: 60-1200	5 to 10kHz
Meteor Reflection	25-75MHz, or higher	20-1000	Limit not definite, but probably approx. 0.1MHz
Obstructed Path Relay	No definite limits. Most useful est: 50-5,000MHz	Up to 200 per Hop est	Unknown, but comparable with Line-of-Sight System
Line-of Sight Relay	Usually applied to above 100MHz	Up to 30-50 per Hop: No Fixed limit on system strength	20-30MHz
Tropospheric Scatter and Ducting	40-10,000MHz	700-800	Approx. inversely proportional to square or cube of path length
Satellite	100-10,000MHz	Global	Limited by Satellite Transmitter Power

of mediums for which telecommunications systems were developed and implemented from the 1950's through the 1970's.

As the demand for spectrum increased to accomodate more and more users, it was apparent that new tools had to be developed. The tools at hand were those of operations research and systems engineering. They were necessitated by the increasing liklihood of electromagnetic incompatibilities between communications electronics equipment and systems. The application of these tools became the basis for Spectrum Engineering. The principles of Spectrum Engineering were first set forth in "Spectrum Engineering - the Key to Progress" (The Joint Technical Advisory Committee, IEEE, March 1968), a report on technical policies and procedures recommended for increased spectrum utilization. This report, containing over a thousand pages, enunciated the technical methods which should be applied for obtaining more efficient use of the electromagnetic spectrum. This text is a statement of how these methods have come to be applied.

The final step in the evolution of the development of modern spectrum management techniques occurred with the implementing of the recommendations of the President's Task Force on Communications Policy. Chapter Eight of the Task Force Report is devoted to the Use and Management of the Electromagnetic Spectrum. It concludes: *greater attention to individual spectrum uses should be achieved through Spectrum Engineering and related technical considerations.*[5] This recommendation has been coming to fruition since the establishment of the office of Telecommunications Policy in 1970.

1.3 U.S. NATIONAL STRUCTURE OF SPECTRUM MANAGEMENT

The structure for national management of the radio spectrum is indicated in Fig. 1.2. This management function embraces the establishment of national objectives, the formulation and enunciation of national policies designed to assist in achieving national objectives, and the execution of those policies whith respect to the use of the spectrum. It embraces the measures taken to manage, supervise, and regulate the use of frequencies so as to avoid and reconcile conflicting uses and demands upon the spectrum in such a manner as to stimulate the growth of the Nation, and satisfy the growing needs of society. At the same time, it is necessary to provide for spectrum usage where other means of communication are not available or satisfactory; and ensure its availability to serve future requirements in the best interest of the United States.

The United States, consistent with its separation of powers among three equal branches of government and its dedication to free enterprise, has elected to divide this responsibility.

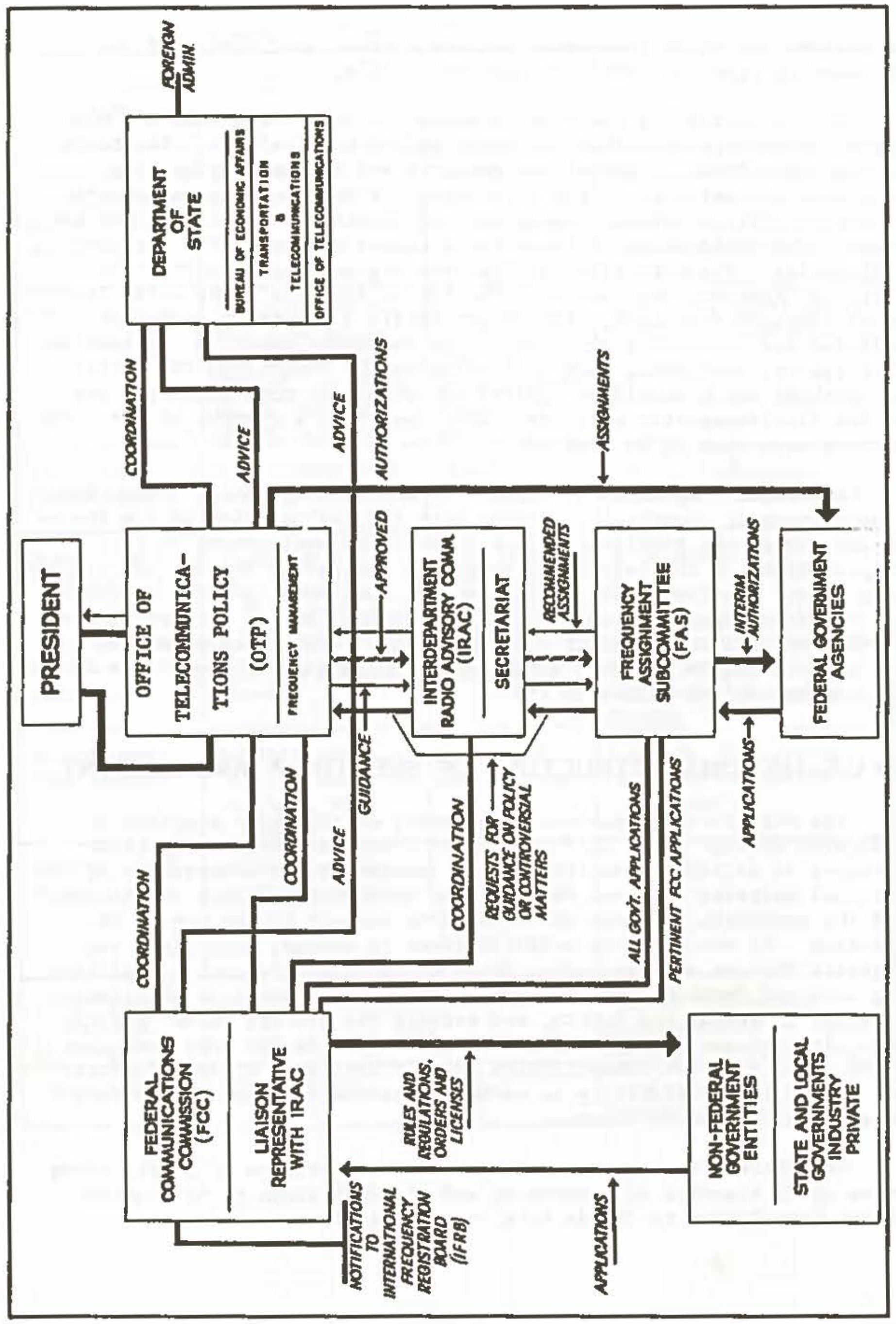


Figure 1.2 - National Frequency Coordination and Assignment.

The Communications Act of 1934, as amended, vests in the Federal Communications Commission (FCC) responsibility for the regulation of non-Government interstate and foreign telecommunications, including the assignment of space in the radio frequency spectrum among private users; regulation of the use of that space; and authorization of alien amateur operators, licensed by their governments, for operation in the United States under reciprocal arrangements.

The Act, in recognition of the Constitutional powers of the Presidency, exempts radio stations belonging to and operated by the United States from the provisions of Sections 301 and 303 (the licensing and General Powers of the Commission) of the Act; and provides that such stations shall use such frequencies as shall be assigned by the President (47 U.S.C. 305(a)). The Act empowers the President, provided he determines it to be in the national interest, to authorize foreign governments to construct and operate radio stations in the fixed service at the United States seat of government; and to assign frequencies thereto (47 U.S.C. 305(d)).

The Act vests defense powers over U.S. telecommunications in the President alone; although it implies in the preamble that the FCC has a direct interest in the management of telecommunications for defense purposes (47 U.S.C. 606).

The functions of other entities within this structure are:

1.3.1 The President

The President, in addition to the foregoing, as Chief Executive and Commander-in-Chief of the Armed Forces of the United States, has the broad responsibility for U.S. use of the telecommunication resource to meet the changing needs of national security, defense and welfare. He uses several government agencies, the principle one of which is the Office of Telecommunications Policy, to assist him in the discharge of his telecommunications responsibilities.

1.3.2 The Office of Telecommunications Policy (OTP)

By Executive Order 11556,[7] the President redelegated his authority (provided by Sec. 305A of the Communications Act of 1934) to the Director of the Office of Telecommunications Policy. Specifically, this includes the functions of amending, modifying, and revoking frequency assignments for radio stations belonging to and operated by the United States. Also provided for is the continuance of the Interdepartment Radio Advisory Committee (IRAC) to serve and assist the Director in an advisory capacity. The structure of OTP is presented in Fig. 1.3

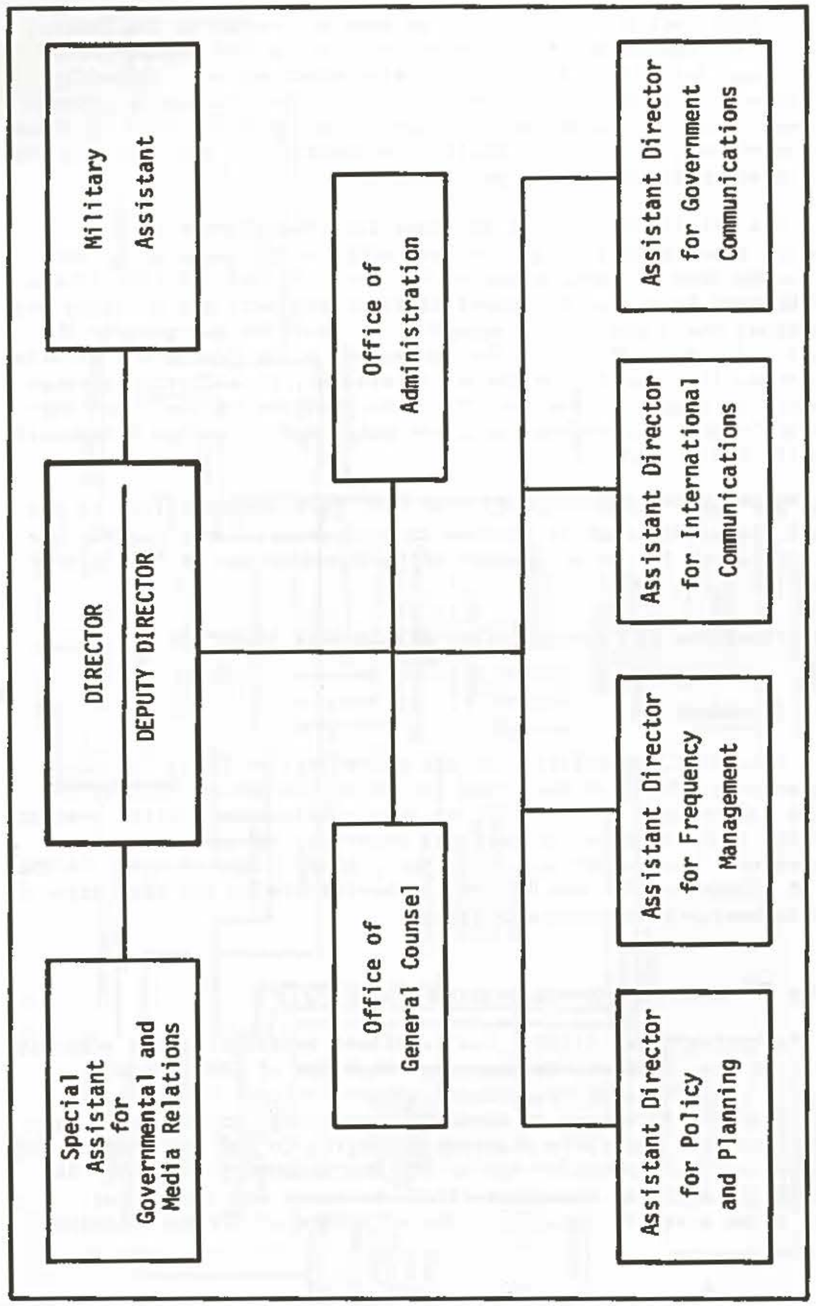


Figure 1.3 - Organization Chart for Office of Telecommunications Policy

OTP is program-oriented with a senior staff composed of four Assistant Directors, a General Counsel, and certain Special Assistants. It receives external support from the following advisory committee and councils whose relation to OTP is illustrated in Fig. 1.4.

1.3.2.1 Frequency Management Advisory Council

This council is composed of widely recognized knowledgeable persons from outside the Government. It gives views of the private sector, and fresh appraisals and practical advice on the government's programs, policies, procedures and practices in frequency.

1.3.2.2 Electromagnetic Radiation Management Advisory Council

The Electromagnetic Radiation Management Advisory Council (ERMAC) was established on December 11, 1968, to advise and make recommendations to the Director of OTP on side effects and in the adequacy of control of electromagnetic radiation arising from communication activities. It reviews, evaluates and recommends potential measures to investigate and mitigate possible undesirable effects on the environment, biological and physical, including equipment and materials, and develops recommended policy guidance in these areas.

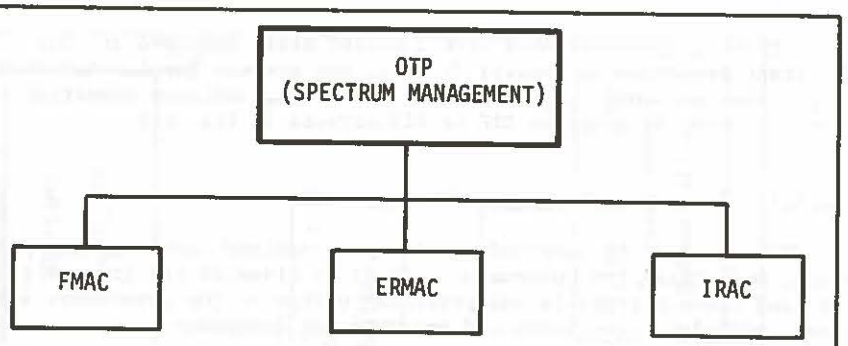
1.3.2.3 Interdepartment Radio Advisory Committee (IRAC)

The IRAC is the principle advisory group to the OTP. Its mission is to assist the Director of the OTP in the discharge of his responsibilities pertaining to the use of the electromagnetic spectrum. In this regard, its basic functions are to assist in assigning frequencies to U.S. Government radio stations. and in developing and executing policies, programs, procedures, and technical criteria pertaining to the allocation, management, and use of the spectrum.

The IRAC's substructure consists of the Frequency Assignment Subcommittee (FAS), the Spectrum Planning Subcommittee (SPS), the Technical Subcommittee (TSC), the International Notification Group (ING), and also has an associated secretariat. In addition, the IRAC has, from time to time, various ad hoc groups. The substructure of the FAS consists of the Aeronautical Assignment Group (AAG), the Military Assignment Group (MAG), and various working groups. The membership in these groups by various Federal agencies and departments is shown in Table 1.3.

1.3.2.3.1 The Frequency Assignment Subcommittee (FAS)

The normal function of the FAS is to carry out activities related



FMAC— — FREQUENCY MANAGEMENT ADVISORY COUNCIL
HIGH LEVEL INDUSTRY LEADERS--RAND, BROADCASTERS, GE, PENN STATE, COMSAT, RCA, FCC CHIEF ENGINEER, AT&T

ERMAC— — ELECTROMAGNETIC RADIATION MANAGEMENT ADVISORY COUNCIL
INDIVIDUALS FROM GOVERNMENT, INDUSTRY AND UNIVERSITIES EXPERT IN THE FIELDS OF MEDICINE AND BIOLOGY

IRAC— — INTERDEPARTMENT RADIO ADVISORY COMMITTEE
GOVERNMENT DEPARTMENTS AND AGENCIES WITH A MAJOR USE OF RADIO FREQUENCIES.

Figure 1.4 - OTP Advisory Councils

to the assignment and coordination of radio frequencies, and the development and execution of procedures therefor. The AAG, chaired by the Federal Aviation Administration, is authorized to take interim action, on behalf of the FAS, on certain assignment requests in the following bands:

200-285 kHz
285-325 kHz (aeronautical radionavigation service only)
325-415 kHz
75 MHz
108.000-121.9375 MHz
123.575-128.8125 MHz
132.0125-136.000 MHz
328.600-335.400 MHz
978-1020 MHz inclusive
1030 MHz
1157-1213 MHz inclusive

The MAG, chaired by the Department of the Air Force, is authorized to take interim action on behalf of the FAS, on certain assignment in the bands 225.0-328.6 and 335.4-399.9 MHz.

Table 1.3 - IRAC Membership

	IRAC	FAS	SPS	TSC	ABBR.	DEPARTMENT OR AGENCY
	X	X	X	X	A	Agriculture
	X	X	X	X	AEC	Atomic Energy Commission
	X	X	X	X	AF	Air Force
					AOTC	Architect of the Capitol
	X	X	X	X	AR	Army
	X	X	X	X	C	Commerce
	X	X	X	X	CG	Coast Guard
					CIA	Central Intelligence Agency
					CPSC	Consumer Products Safety Commission
					CSC	Civil Service Commission
					EPA	Environmental Protection Agency
	X	X	X	X	FAA	Federal Aviation Administration
	L	M/L	L	L	FCC	Federal Communications Commission
					FEA	Federal Energy Administration
#					FRS	Federal Reserve System
					GPO	Government Printing Office
	X		X		GSA	General Services Administration
	X	#	X		HEW	Health, Education and Welfare
					HR	House of Representatives
					HUD	Housing and Urban Development
	X	X	X	X	I	Interior
#					IBWC	International Boundary & Water Commission
	X	X	X	X	J	Justice
					L	Labor
					LC	Library of Congress
	X	X	X	X	N	Navy
	X	X	X	X	NASA	National Aeronautics & Space Administration
##					NCHA	National Capitol Housing Authority
		X			NSA	National Security Agency
	X		X		NSF	National Science Foundation
					OMB	Office of Management and Budget
	X		X		S	State
					SC	Supreme Court
					SI	Smithsonian Institution
	X	X	X	X	T	Treasury
#					TRAN	Transportation
#					TVA	Tennessee Valley Authority
					USCP	U.S. Capitol Police
	X	X	X	X	USIA	U.S. Information Agnecy
		X			USPS	U.S. Postal Service
	X	X	X	X	VA	Veterans Administration

M, X = member
L = liaison
# = represented by some other member
= no longer in Federal Government. Transferred to District Government by Home Rule Bill

1.3.2.3.2 The Spectrum Planning Subcommittee (SPS)

The SPS is responsible to the IRAC for carrying out functions that relate to planning the use of the electromagnetic spectrum in the national interest. This includes the apportionment of spectrum space for the support of established or anticipated radio services, as well as the apportionment of spectrum space between or among government and non-government activities. In carrying out these functions, it utilizes the following techniques:

(a) Maintains a continuing appraisal of the current and future needs of the various radio services, and makes recommendations for changes in the Table of Frequency Allocations or other actions, as appropriate;

(b) Undertakes preparatory work relating to frequency allocation matters for international conferences.

(c) Develops procedures enabling the Subcommittee to ensure electromagnetic compatibility among electronic systems through observance of the provisions of the systems review procedure spelled out in the OTP Manual of Regulations and Procedures for Radio Frequency Management (see paragraph 2.7).

1.3.2.3.3 The Technical Subcommittee (TSC)

The TSC carries out functions related to the technical aspects of the use of the electromagnetic spectrum. In this regard, the TSC:

(a) Develops recommended new standards and improvements of existing standards pertaining to use of the radio spectrum;

(b) Maintains awareness of the radio propagation and related investigations (including, for example, natural radio noise measurement and analysis programs), and the needs of the government, for purposes of evaluating and making recommendations leading to better utilization of the radio spectrum;

(c) Evaluates and makes recommendations, in the form of technical reports, on new and existing techniques from the standpoint of their ability to optimize use of the radio spectrum (recommendations to include implementation steps);

(d) Provides a coordination and evaluating mechanicsm for activities within the government dealing with the biological and non-biological effects of non-ionizing electromagnetic radiation, and;

(e) Evaluates and makes recommendations, in the form of technical reports, regarding the EMC capabilities and needs of the

government in support of spectrum management, including techniques and criteria leading to greater inter-and intra-service sharing of available spectrum; and to the reduction of man-made radio noise.

The TSC conducts its activities in the following permanent working groups:

- Standards
- Propagation
- Techniques
- Side Effects
- Electromagnetic Compatibility

1.3.3 The State Department

The Department of State has the responsibility for the formulation of U.S. positions for projection internationally, their negotiation, and the international coordination and registration of U.S. use of radio frequencies. The Department relies upon the Director of Telecommunications Policy and the Federal Communications Commission. It should be noted that OTP is charged in Executive Order 11556 to assist and advise the Department of State in the discharge of its function in the field of international telecommunications for most matters. It relies upon the IRAC/FCC in matters involving the International Telecommunications Union (ITU), International Frequency Registration Board, and upon the Federal Aviation Administration with respect to International civil Aviation Organization (ICAO) matters. Additionally, there are provisions for radio frequency coordination included in a large number of bilateral and some multilateral (e.g., NATO) agreements. For example, the U.S. military forces coordinate their large overseas use of frequencies through military channels with their counterparts in the countries concerned. Similarly, the Voice of America coordinates its frequency uses directly with officials of the countries involved.

The State Department chairs and provides the secretariat for the U.S. National Preparatory Committee for the International Radio Consultative Committee (CCIR), an organ of the ITU with the duty to study technical and operating questions relating specifically to radio communication. It calls upon government agencies having primary responsibility or interest when specialized matters are involved. As with frequency management, the IRAC mechanism contributes substantially to the preparatory work for the CCIR, serving as the reviewing activity for the OTP prior to concurrence in U.S. position papers for department of state use in international negotiations.

1.3.4 The Federal Communications Commission (FCC)

The Commission is an independent Federal agency composed of seven members appointed by the President, by and with the advice and consent of the Senate. The Chairman, designated by the President, serves as

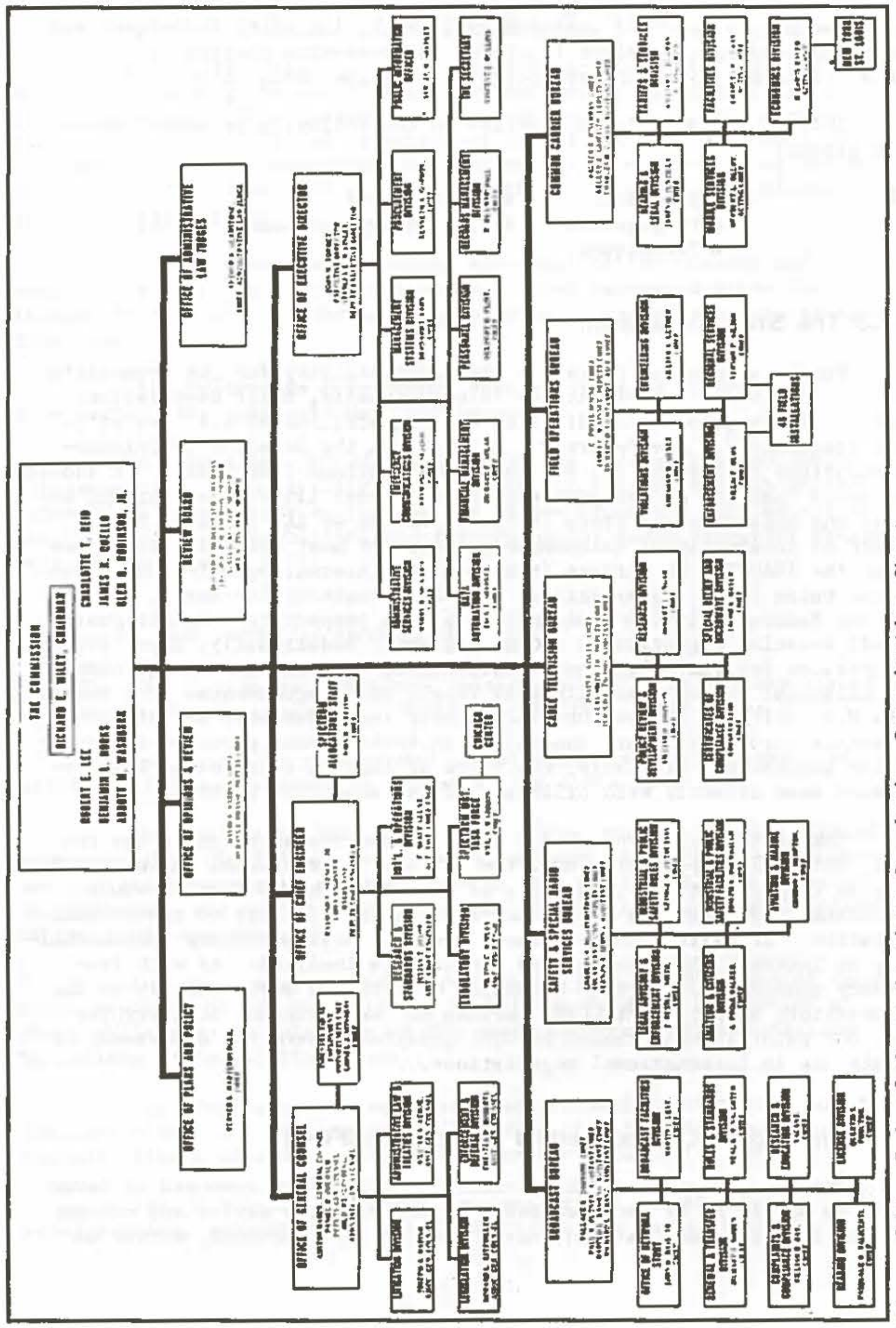


Figure 1.5 - Federal Communications Commission Organization Chart.

Table 1.4 - Federal Communication Commission Rules and Regulations

Part	Title
0	Commission organization
1	Practice and procedure
2*	Frequency allocations and radio treaty matters; general rules and regulations
5*	Experimental radio services (other than broadcast)
13	Commercial radio operators
15*	Radio frequency devices
17	Construction, marking, and lighting of antenna structures
18*	Industrial, scientific, and medical equipment
19	Employee responsibilities and conduct
21*	Domestic public radio services (other than maritime mobile)
23*	International fixed public radiocommunications services
25*	Satellite communications
31	Uniform system of accounts for Class A and Class B telephone companies
33	Uniform system of accounts for Class C telephone companies
34	Uniform system of accounts for radiotelegraph carriers
35	Uniform system of accounts for wire-telegraph and ocean-cable carriers
41	Telegraph and telephone franks
42	Preservation of records of communication common carriers
43	Reports of communication common carriers and certain affiliates
51	Occupational classification and compensation of employees of Class A and Class B telephone companies
52	Classification of wire-telegraph employees
61	Tariffs
62	Applications to hold interlocking directorates
63	Extension of lines and discontinuance of service by carriers
64	Miscellaneous rules relating to common carriers
66	Applications relating to consolidation, acquisition, or control of telephone companies
73*	Radiobroadcast services
74*	Experimental, auxiliary, and special broadcast services
76	Cable television service
78	Cable television relay service
81*	Stations on land in the maritime services
83*	Stations on shipboard in the maritime services
87*	Aviation services
89*	Public safety radio services
91*	Industrial radio services
93*	Land transportation radio services
94*	Private operational-fixed microwave radio service
95*	Citizens radio service
97*	Amateur radio service
99*	Disaster communication service

the chief executive and administrative functions, except those which, because of their program importance, are performed by the full commission. The substantive functions are executed by the Commission; and by delegation of authority, through panels of commissioners, individual commissioners, five integrated operating bureaus, and several staff units (see Fig. 1.5). The management of the spectrum is carried out within each of the service-oriented operating bureaus. The office of the Chief Engineer maintains liaison with the IRAC. The FCC carries out its regulatory function through the issuing, withholding, or revoking of licenses of radio stations in the private sector.

In contrast to the management of the spectrum in the federal government, there is no single focus for spectrum management in the Federal Communications Commission. The FCC is basically organized in accordance with the services it regulates. This regulation is carried out through the licensing procedure in each of the individual bureaus.

The FCC has approximately 60 major organizational entities, including bureaus, divisions, and specialized task forces. Almost half of these perform some spectrum management functions.

The techniques associated with the management functions are broad and varied. They are manifested in the Rules and Regulations of the FCC. Table 1.4 is a list of the 40 parts of these Regulations. An asterisk is next to those parts which bear on the use of the spectrum.

These rules are developed and promulgated under the provisions of the Communications Act of 1934, as amended, and the Administrative Procedures Act. With regard to the former, the Congress, in the Communications Act of 1934, (1) provided that "so as to make available, so far as possible, to all the people of the United States a rapid, efficient, nationwide, and worldwide wire and radio communication service, with adequate facilities of reasonable charges, for the purpose of national defense; for the purpose of promoting safety of life and property through the use of wire and radio communications". Also, (2) the Federal Communications Commission was created to execute and enforce the provisions of the Act. Sections 301 and 303 of the Act, set forth the general powers of the Commission to regulate radio stations, and stipulate that such stations cannot be operated except under and in accordance with the Act, and with a license granted under the provisions of the Act. The Congress, by Section 305 of the Act, excluded radio stations belonging to and operated by the United States from the provisions of Sections 301 and 303 of the Act. It provided that all such stations shall use frequencies as assigned by the President.

The Congress declared in the Communications Satellite Act of 1962: (3) "it is the policy of the United States to establish, in conjunction and in cooperation with other countries, as expeditiously as practicable, a commercial communications satellite system, as part of an improved global communications network, which will be responsible to public needs

and national objectives, which will serve the communication needs of the United States and other countries, and which will contribute to world peace and understanding...United States participation in the global system shall be in the form of a private corporation, subject to appropriate governmental regulation...It is not the intent of Congress by this Act to preclude the creation of additional communications satellite systems, if required in the national interest".

With regard to the latter, the FCC, is required by law to carry out its regulations in accordance with a specified set of Administrtive Procedures. This is not the case within the Federal Government. Adhering to these procedures provides every opportunity for comment by the public prior to implementation of Rules and Regulations. While this is desirable in a democracy, it does delay implementation of new management techniques.

1.3.5 The Office of Telecommunications (OT) Department of Commerce

Reorganization Act No. 1 of 1970, which created the Office of Telecommunications Policy, also created the Office of Telecommunications in the Department of Commerce. Its principle function was to provide a support capability to OTP in the area of Spectrum Management. OT's support of the federal government spectrum management structure includes engineering, analysis and administrative efforts. The specific objectives of this support capability are described in the sections below.

1.3.5.1 Spectrum Engineering Development

The support in this area is devoted to the obtaining of information on how the electromagnetic spectrum is actually being utilized. Such information is of value in such functions as compliance, occupancy, and compatibility. In this regard, the facility indicated discussed in Chap. 5 is used to obtain measurements of spectrum usage and emission characteristics.

1.3.5.2 Spectrum Management and Information

This activity is concerned with the administrative and routine technical support required in the review and processing of 60,000 annual federal government frequency assignment actions. These actions include the addition, removal and modification of over 125,000 assignment records of federal government agencies; and the operation and maintenance of a computerized Government Master File (GMF). In addition, support is provided in the review of new radiocommunication systems, for various IRAC subcommittees and for the ad hoc planning groups. Related data bases are maintained on communication-electronic equipment characteristics of federal government spectrum users; as well as lists

of authorized non-government spectrum users, and international frequency assignments involving approximately 1,100,000 entries.

1.3.5.3 Spectrum Analysis

This activity is concerned with both near-term and long-term analyses of spectrum sharing among individual radio stations and major systems. In this regard, particular attention is given to new systems prior to their implementation in an operational mode. The spectrum management techniques applied in this function, are supportive of the systems review procedure which is elaborated on in Chap. 4.

In addition to individual problems, the spectrum analysis function includes investigations of certain frequency bands and radio services to determine the efficiency and effectiveness of prevailing spectrum sharing arrangements, and the identifying of alternative improvements. Illustrations of the types of radio links which would be included in the analyses for a particular band and the techniques used in such analyses are elaborated on in Chap. 6.

1.4 THE INTERNATIONAL STRUCTURE OF SPECTRUM MANAGEMENT

The principle international body concerned with the mangement of the electromagnetic spectrum is the International Telecommunications Union (ITU). This body is the oldest international organization in existence today. Its functions are to:

(a) Affect the allocation of the radio frequency spectrum and the registration of radio frequency assignments in order to avoid harmful interference between radio stations of different countries;

(b) Coordinate efforts to eliminate harmful interference between radio stations of different countries, and to improve the use made of the radio spectrum;

(c) Foster collaboration among its members and associate members with a view to the establishment of rates at levels as low as possible, consitent with an efficient service, and taking into account the necessity for maintaining independent financial administration of telecommunications of a sound basis;

(d) Foster the creation, development, and improvement of telecommunication equipment and networks in new or developing countries by every means at its disposal, especially in participation in the appropriate programs of the United Nations.

(e) Promote the adoption of measures for ensuring the safety of life through the cooperation of telecommunications services;

(f) Undertake studies, makes regulations, adopts resolutions, formulates recommendations and opinions, and collects and publishes information concerning telecommunication matters for the benefit of all members and associate members.

The structure of the Union is indicated in Fig. 1.6. Those parts of it which impact the use of the electromagnetic spectrum are connected with dashed lines. Internationally, spectrum management is carried out using three techniques:

1) Adherence to internationally-agreed technical criteria;

2) Coordination of electromagnetic signals which cross international boundries; and

3) The international allocation of electromagnetic spectrum.

The first and second are embodied in the CCIR, International Radio Consultative Committee, and IFRB, International Frequency Registration

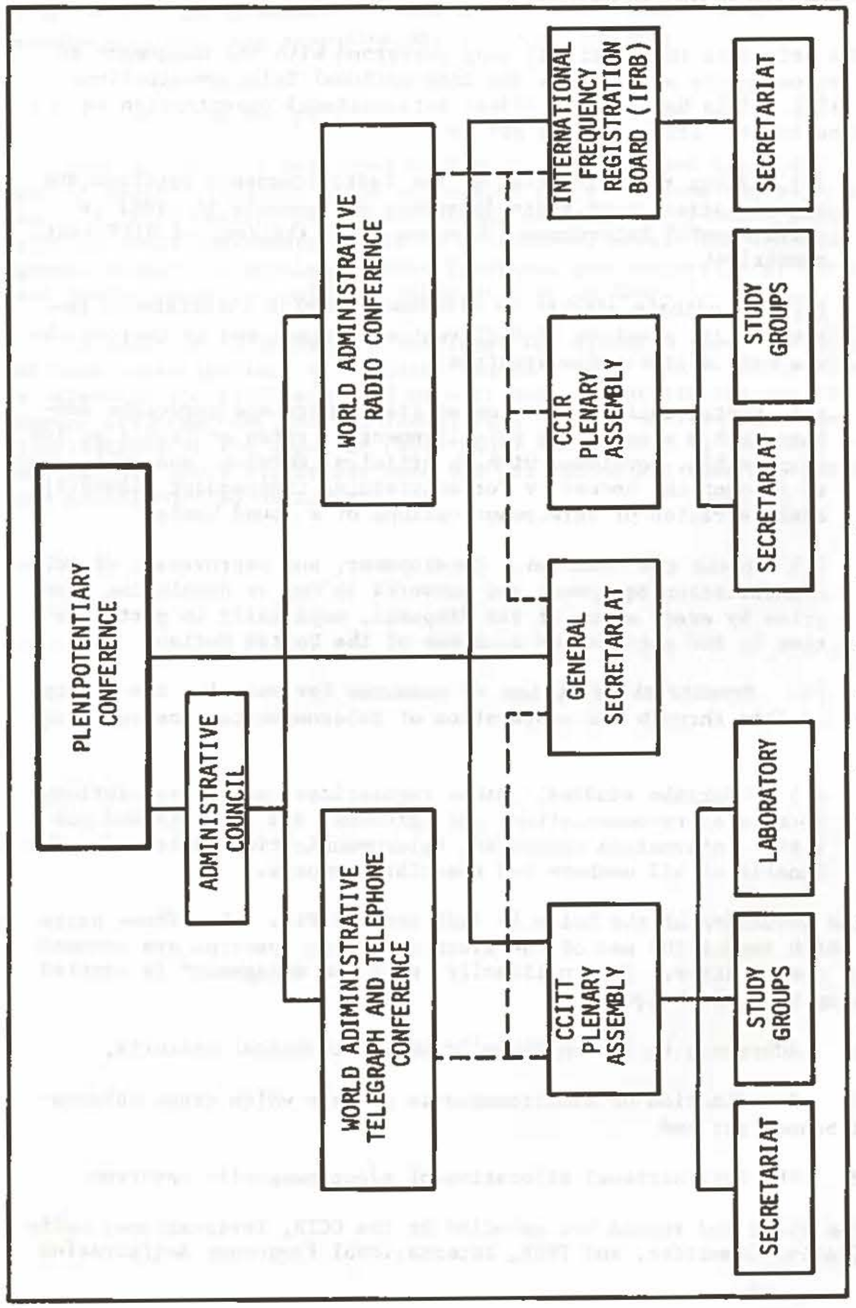


Figure 1.6 - International Telecommunication Union Organization.

Board, respectively; the third occurs during World Administrative Radio Conferences (WARC's).

1.4.1 The Plenipotentiary Conference

The Plenipotentiary Conference, the supreme organ of the Union, which meets normally every five years, is composed of delegations representing members and associate members. Its last meeting was held in Torremolinos, Spain, in 1973. Such conferences determine the general policies of the Union, review reports of the Administrative Council, establish the basis for the budget of the Union, supervise the financial aspects of the Union, elect the members of the Union which are to serve on the Administrative Council, as well as the Secretary-General and Deputy Secretary-General, and revise the Convention as considered necessary.

1.4.2 World Administrative Radio Conference (WARC's)

The third major objective of international spectrum management is allocation of the spectrum. This is carried out at World Administrative Radio Conferences. It is only at such conferences that the Radio Regulations may be modified. Normally, such conferences are of a specialized nature, dealing with only one aspect of the Radio Regulations, such as Aeronautical, Maritime, Space, or Broadcasting. However, from time to time, at approximately 20 year intervals, the entire body of the Regulations may be considered for revision.

World Administrative Radio Conferences are basically planning conferences. They are convened in order to modify the Radio Regulations to accomodate changes in the use of the spectrum and to consider specific telecommunication matters, such as the revision of the Administrative Regulations. The International Radio Regulations stem from the decisions of World Administrative Radio Conferences.

1.4.2.1 Preparatory Process

As spectrum management technique, the preparation, participation in, and implementation of the results of these conferences provide the means to allocate spectrum and develop new technical criteria for sharing between services. Because of the importance of such conferences, preparation of the positions of the U.S. and other countries for them are begun two to five years before their actual convening.

1.4.2.2 Terms of Reference

The procedures for preparing for Administrative Radio Conferences are complex and time consuming. These conferences may discuss only

items included in their agenda, which are determined by the ITU Administrative Council with the concurrence of a majority of the members of the Union. They may include any question directed by a Plenipotentiary Conference.

1.4.2.3 U.S. Position Preparation

Proposed agenda items and the U.S. positions with respect thereto, are developed by the IRAC/FCC mechanism for effecting intra-U.S. coordination. When completed, these are sent to the Department of State for use by the U.S. representative to the ITU Administrative Council. Upon receipt through the State Department of an approved agenda for the forthcoming ITU Administrative Radio Conference; the OTP, with the assistance of IRAC and FCC develops the proposals, positions, and instructions to the U.S. delegation for use by the Department of State.

The United States has had considerable success through the development of *Preliminary Views* on each agenda item, and exchange of views with members of the Union through meetings with friendly interests. Following these exchanges, receipts of comments in response to FCC Public Inquiry on the Preliminary Views, and consideration of new developments; the OTP and FCC develop the U.S. proposals to the Conference, with alternative positions and instructions to the U.S. Delegation. This documentation is then provided to the Department of State. In nearly all cases, the IRAC/FCC mechanism is used.

1.4.2.4 Delegation Formation

As a final step in the preparation for a conference, the State Department designates the delegation that will actually represent the United States. The Department sometimes convenes a Government-Industry Group to assist in the final preparation of the U.S. proposals.

1.4.2.5 Inplementation

Following an Administrative Conference, the OTP and the FCC identify the actions needed to implement the U.S. international obligations undertaken at the conference; and recommend courses of action to carry out the results of the conference. Concurrently, the Department of State prepares the necessary documents for the President to obtain the consent and advice of the Senate for his ratification of the conference results.

1.4.3 The Administrative Council

The Administrative Council, consisting of 36 members of the union chosen with due regard for equitable representation of all parts of the world, meets anually to carry out the administrative functions of the union.

1.4.4 The Secretary-General

The Secretary-General directs the General Secretariat and is responsible to the Administrative Council for the administrative and financial aspects of the union, and coordinates the activities of the union's permanent organ.

1.4.5 The International Frequency Registration Board (IFRB) and the International Radio Consultive Committee (CCIR)

The international responsibilities for effective utilization of the electromangetic spectrum reside in the ITU. Within the ITU structure, the CCIR and the IFRB have the responsibility for carrying out this function. The International Telecommunications Convention, Malaga-Torremolinos, 1973,describes the purposes of these organizations, and is quoted as follows:

> "The duties of the International Radio Consultative Committee (CCIR) shall be to study technical and operating questions relating specifically to radio communication, and to issue recommendations on them".

> "The essential duties of the International Frequency Registration Board shall be:
>
> a. to effect an orderly recording of frequencies made by the different countries, so as to establish, in accordance with any decision which may be taken by competent conferences of the union, the date, purpose and technical characteristics of each of the assignments, with a view to ensuring formal international recognition thereof;
>
> b. to effect in the same conditions and for the same purpose, and orderly recording of the positions assigned by countries to geostationary satellites;
>
> c. to furnish advice to members with a view to the operation of the maximum practicable number of radio channels in those portions of the spectrum where harmful interference may occur, and with a view to the equitable, effective, and economical use of the geostationary satellite orbit.

c. to furnish advice to members with a view to the operation of the maximum practicable number of radio channels in those portions of the spectrum where harmful interference may occur, and with a view to the equitable, effective, and economical use of the geostationary satellite orbit.

d. to perform any additional duties concerned with the assignment and utilization of frequencies and with the procedures provided for in the Radio Regulations; and as prescribed by a competent conference of the union, or by the Administrative Council with the consent of a majority of the members of the union, in preparation for, or pursuance of the decisions of such a conference".

The structure of these two organizations is indicated in Figs. 1.7 and 1.8. The CCIR has eleven study groups dealing with all technical aspects of telecommunications systems dependent on the radio spectrum for their functioning, and influences the use of radio through its reports and recommendations. While all member administrations of the ITU may participate, approximately 20 make the principle contributions. These reports and recommendations carry great weight because they represent the worldwide consensus with regard to the technical parameters which may be achieved by existing telecommunications technology. The technical criteria adopted at three year intervals by the CCIR may or may not be incorporated into the Radio Regulations by a World Administrative Radio Conference. When they are, they take on the force of international law. For example; as a result of the WARC-ST, 1971, some CCIR criteria are now embodied in Sections VII and VIII of Article 7 of the Radio Regulations.

The basis for the functions carried out by the IFRB are the reports and recommendations of the CCIR and the Radio Regulations specified in Articles 9 and 9A. These set forth the technical, rational, and the methodology for determining the existence of harmfully interfering telecommunications operations among electromagnetic signals emanating from different countries. The IFRB does not have power to force a country to terminate its operation. It is, however, normally in the interests of the several countries who may be concerned to work out a mutually-acceptable solution. After notification by a particular administration of its intended use of a specific frequency, with technical substantiation that the planned use will not cause harmful interference, the frequency is then given international recognition and becomes part of the International Frequency List (IFL).

In accomplishing this, two of the three objectives of International Spectrum Management have been achieved. They are spectrum registration and regulation of spectrum use. These are used to enhance the smooth flow of radio telecommunications among nations. The third objective, spectrum allocation, has been treated in paragraph 1.4.2.

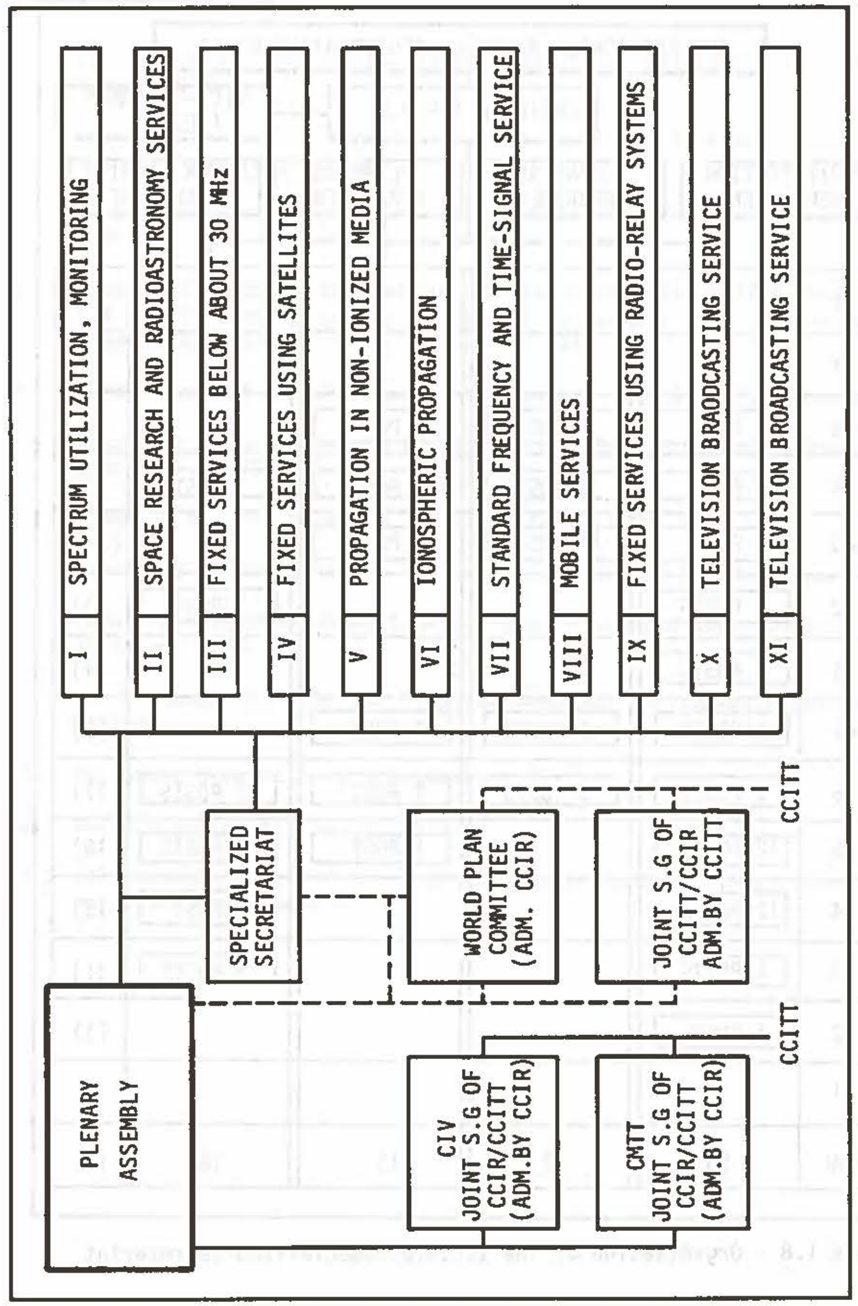
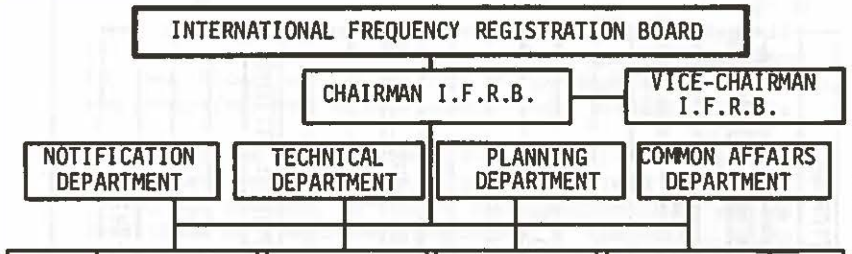


Figure 1.7 - Organization Chart of the CCIR



D2					
D1					
P5	1 POST	1 POST	1 POST		(3)
P4	1 POST	2 POSTS	3 POSTS	1 POST	(7)
P3	1 POST	14 POSTS	6 POSTS		(21)
P2	3 POSTS			1 POST	(4)
P1	4 POSTS				(4)
G7	6 POSTS	2 POSTS	1 POST		(9)
G6	6 POSTS	3 POSTS	1 POST	7 POSTS	(17)
G5	12 POSTS		1 POST	3 POSTS	(16)
G4	12 POSTS			1 POST	(13)
G3	6 POSTS			5 POSTS	(11)
G2	1 POST				(1)
G1					
TOTAL	53	22	13	18	106

Figure 1.8 - Organization of the I.F.R.B. Specialized Secretariat

1.5 REFERENCES

1. International Telecommunications Convention, Malaga-Torremolinos, Spain, 1973

2. International Radio Regulations, International Telecommunications Union, Geneva Switzerland.

3. Radio Spectrum Conservation, McGraw-Hill Book Company, New York, 1952. pp. 6-7 Joint Technical Advisory Committee.

4. "Identification of Information and Associated Analytical Techniques for Solution of Frequency Management Problems"; Vol. II; Sachs/Freeman Associates, Inc., February. 1971.

5. "The Nature of the Problem"; D.M. Jansky, IEEE EASCON, October 1974.

6. Manual of Regulations and Procedures for Radio Frequency Management; OTP, 1975.

7. Managing the Use of Radio in the United States; OTP, 1975.

8. Report of the President's Communications Policy Board; March 1951.

9. Final Report, Presidents Task Force on Communications Policy, December, 1968.

10. The Communications Act of 1934, as amended; Government Printing Office.

11. Executive Order 11556; 9 September, 1970.

12. Reorganization Act No. 1, 1970.

13. 1975 Annual Report of the Interdepartment Radio Advisory Committee; Department of Commerce.

CHAPTER 2

OPERATIONAL METHODS OF SPECTRUM MANAGEMENT

One of the fundamental aspects of spectrum management is the method used to obtain authorization to operate a radio station. For Federal Government radio stations, this is done by obtaining an assignment from the Office of Telecommunications Policy (OTP). For all other radio stations; i.e., those in the private sector and state and local governments, this is accomplished by obtaining a license. This chapter will describe the techniques used in the assigning and licensing processes.

2.1 ASSIGNMENT FOR FEDERAL GOVERNMENT RADIO STATIONS

This section describes how Federal Government radio stations obtain assignments, the principles used for determining which stations do and do not receive assignments, and a description of operational methods used in different radio services.

The objectives of federal frequency assignment are to:

- meet the frequency requirements essential to the missions of government agencies;

- take into account the potential impact on other spectrum occupants.

The manual of Regulations and Procedures for Radio Frequency Management of OTP sets forth the rules to be followed in order to obtain an authorized frequency assignment. Section 8.1 of this Manual sets forth the General Procedure for Authorizing Frequency Usage as follows:

> "Applications that have been screened and accepted are processed for the agenda of the Frequency Assignment Subcommittee (FAS). A computer program arranges the agenda in frequency sequence, and assigns a docket number to each application for identification and reference. The application particulars are included in a weekly agenda section, which is distributed and the FCC for study. The Department of Commerce Office of Telecommunications

reviews the Government applications to ensure adequate justification and compliance with policy and regulations to determine technical appropriateness and probability of major problems, and to ascertain whether there are conflicts with nonmembers of the IRAC".

"Each month the FAS/FCC considers pending items and takes agreed action within policy guidance. When policy guidance is needed, or an agreement cannot be reached, or the IRAC has so directed, or an agency so requests, applications are referred to the IRAC/FCC. Matters which cannot be resolved within the IRAC/FCC, or when so directed by the Office of Telecommunications Policy (OTP), or requested by an agency, are referred to the Assistanct Director for Frequency Management, OTP, who resolves them or refers them to the Director. Matters of considerable importance, such as changes in the Table of Frequency Allocations, significant Government use of non-Government frequency bands, and advice to the Department of State, are recommended to the OTP for consultation with the FCC or other appropriate agencies. Although Government applications are not heard in public for security reasons, the public is represented by the FCC Liaison Representative who may object, concur, or give tacit approval".

"As soon as possible after each FAS/FCC meeting, the IRAC Secretariat prepares the FAS minutes and submits them to the OTP for approval. After approval, the IRAC Secretariat updates the Government Master File (GMF) from which it prints the list of Frequency Assignments to Government Radio Stations".[1]

There are 43 federal departments and agencies which have frequency authorizations. Table 2.1 shows a list of these as of July 11, 1975. Included on the list are the number of assignments* for each agency, percent of total assignments, and an indication of which agencies have the most frequencies (rank). There are presently over 126,000 assignments.

The Interdepartment Radio Advisory Committee's Frequency Assignment Subcommittee is the principal organization responsible for authorizing frequencies. This organization carries out approximately 5,000 assignment actions each month. Of these, approximately 40 percent are new authorizations, 25% are modifications of existing, and 35% are deletions. Fig. 2.1 is the application form for frequency assignment authorization which is filled out by a government agency requiring a frequency. As is apparent, it requires a considerable amount of detailed technical information. This information is stored in the Government

* A frequency assignment constitutes an authorization to use a specific frequency, in a specific location, with a transmitter(s) having particular characteristics.

Table 2.1 - Selected Government Frequency Assignement Data
(as of July 1, 1975)

Department or Agency	Discrete Freq.*	Freq. Number	Assignmts %	Rank
Agriculture	426	8,009	6.34	7
Air Force	4,536	20,594	16.31	2
Architect of the Capitor	1	1		
Army	2,950	14,203	11.25	4
Civil Service Commission	1	1		
Commerce	602	3,655	2.89	8
Consumer Product Safety Commission	1	1		
Energy Research & Development Admin	834	3,086	2.44	9
Environmental Protection Agency	57	152	.12	
Federal Communications Commission	63	752	.60	
Federal Energy Administration	1	1		
Federal Reserve System	28	74	.06	
General Services Administration	21	199	.16	
Government Printing Office	2	2		
Health, Education & Welfare	102	860	.68	
House of Representatives	2	3		
Housing & Urban Development	3	4		
Interior	1,167	9,943	7.87	6
International Boundary & Water Comm.	16	31	.03	
Interstate Commerce Commission	1	1		
Justice	606	9,982	7.90	5
Labor	13	21	.02	
Library of Congress	2	2		
National Aeronautics & Space Admin.	502	1,122	.90	11
National Capital Housing Authority	3	3		
National Science Foundation	69	106	.09	
National Security Agency	41	49	.04	
Navy	4,265	18,039	14.28	3
Office of Management & Budget	2	2		
Smithsonian Institution	38	45	.04	
State	83	109	.09	
Supreme Court	2	2		
Tennessee Valley Authority	186	889	.71	
Trans.-Coast Guard	827	9,032	7.15	
FAA	1,656	19,665	15.57	
Non-Gov. FAA	531	1,567	1.24	
Other than CG/FAA/NG	100	204	.16	
Treasury	216	1,590	1.25	10
U.S. Capital Police	6	6	.01	
U.S. Nuclear Regulatory Comm.	6	6	.01	
U.S. Postal Service	59	623	.50	
U.S. Information Agency	359	973	.78	12
Veterans Administration	117	531	.42	
Other	94	108	.09	
(do not add * column) Total		126,248	100.00	

Table 2.1 conclusions:

Military Services		41.84
Transportation		24.12
	Total	65.96

Master File (GMF), for each authorization. The specific nature of the information required in each entry is indicated in Sec. 9.8 of the OTP Manual. Differences in the colums are due primarily to the diverse information required for the various types of services. Table 2.2 indicates the types of information to be included in the application form.

Table 2.2 - New Assignment Information

Application Date
Associated Assignments
Security Classification
Desired Frequency
Justification
Bureau/Agency
Type of Station
Emission Designation
Power, Transmitter
Power Density
Transmitter Location
Antenna Location
Antenna Polarization
Receiver Location
Receiver Antenna Characteristics
Current Remarks - Used for unique description information dependent on service and band.

Application for authority to use radio frequency by a U.S. federal government agency must be justified for reasons such as:

a. Specific presidential directive
b. Specific legislative directive
c. International commitments
d. Established mission of an applicant

Unless otherwise indicated, the relative priority between two or more frequency assignments which are substantially equal is determined on the basis of their assignment dates, (i.e., a frequency assignments with later dates). The priority of a mobile station applies only in the geographical area of designation. The priority of a fixed station applies only at the geographical area of the receiver antenna location designated in the frequency assignment.

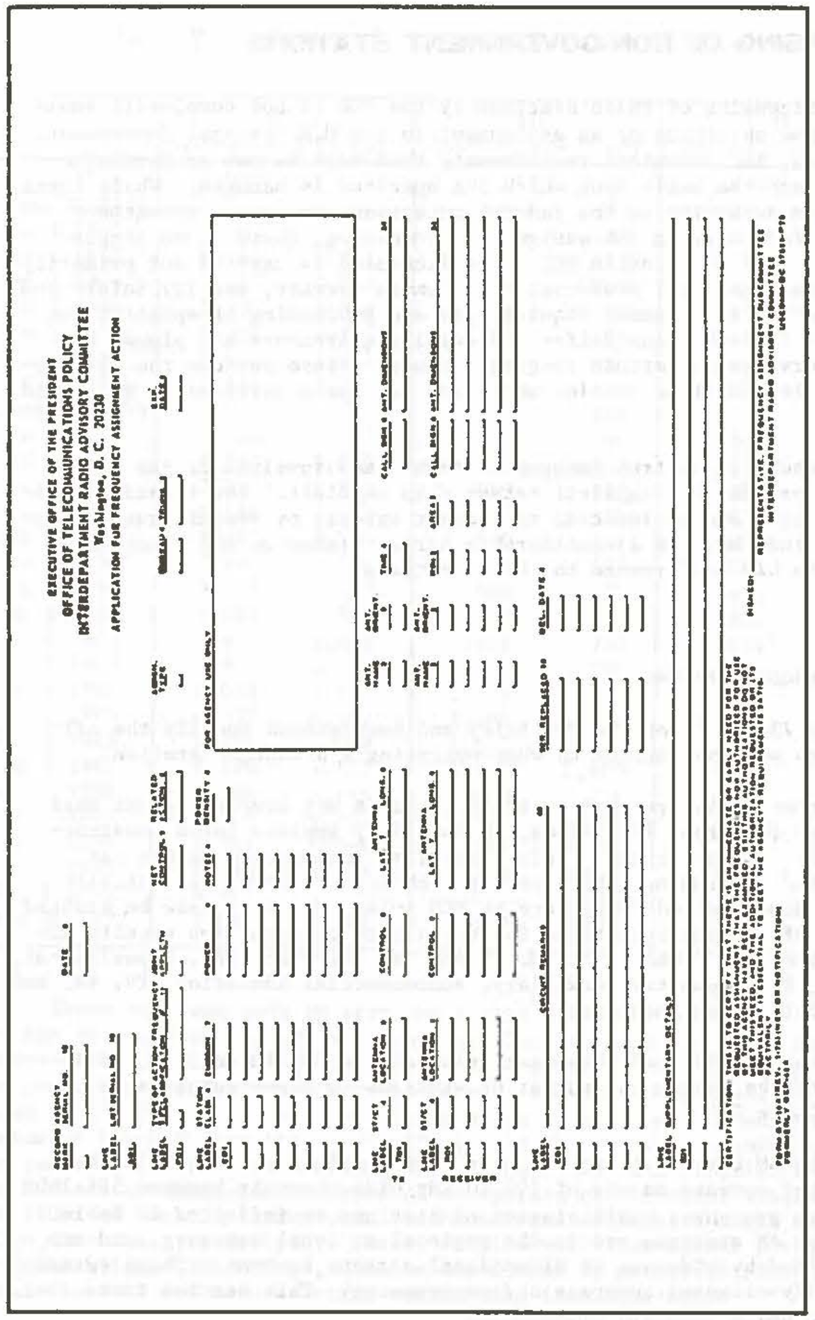


Figure 2.1 - Application for Frequency Assignment Action.

2.2 LICENSING OF NON-GOVERNMENT STATIONS

The licensing of radio stations by the FCC is not completely analogous to the obtaining of an assignment in the U.S. Federal Government. Nonetheless, the technical requirements that must be met in obtaining a license are the basis upon which the spectrum is managed. While there is a single authority in the federal government frequency management structure for carrying out assignment processing, there is no single entity for this function in FCC. The licensing is carried out primarily in three bureaus: (1) Broadcast, (2) Common Carrier, and (3) Safety and Special Services. License requirements and processing of applications in each of these bureaus differ. Special requirements are placed on certain services in certain frequency bands. These include the aeronautical mobile, maritime mobile, and fixed and space services as described below.

In general, spectrum management techniques involved in the FCC licensing process are implicit rather than explicit. The technical criteria utilized are influenced, to a great extent, by administrative convenience; and there is a considerable burden placed on the licensee to demonstrate his conformance to these criteria.

2.2.1 Broadcast Services

Parts 73 and 74 of the FCC Rules and Regulations specify the criteria which must be adhered to when operating a broadcast station.

In order to insure that an applicant does not invest a great deal of money on the wrong facilities, he initially applies for a construction permit, not a license. Only after the construction permit has been granted (following comprehensive technical review), the facility built and demonstrated to conform to FCC rules, may a license be granted. The types of broadcast stations for which such construction permits are required include: Commercial AM, FM and TV, International, Experimental, Facsimile, Developmental, Auxiliary, Noncommercial Education, TV, FM, and AM, Translator, and Booster.

The three principal broadcast services are AM, FM and TV. An indication of the growth and number of stations in these services is shown in Table 2.3.[7]

In the AM service there are over 4500 stations operating in the U.S.A. They operate on one of 107 10 kHz wide channels between 535-1605 kHz. There are three basic classes of stations as indicated in Table 2.4.[6] Most AM stations are in the regional or local category, and are characterized by wide use of directional antenna systems. These permit much locally-oriented coverage and programming. This service comes closest to being *Spectrum Engineered.*

Table 2.3 - Number of Authorized Broadcast Stations

	AM Authorized/On Air		FM Authorized/On Air		TV Authorized/On Air	
Jan 1 1946	1,004				9	6
June 30 1946			456	55		
Jan 1 1947	1,517		918	238		
Jan 1 1948	1,962	1,621	926	458	73	17
Jan 1 1949	2,127	1,912	966	700	124	50
Jan 1 1950	2,234	2,086	788	733	111	97
Jan 1 1951	2,351	2,232	703	676	109	107
Jan 1 1952	2,408	2,331	650	637	108	108
Jan 1 1953	2,524	2,391			273	129
June 30 1953			601	580		
Jan 1 1954	2,636	2,621	580	580	567	356
Jan 1 1955	2,774	2,669	559	552	576	439
Jan 1 1956	2,935	2,824	557	540	590	482
Jan 1 1957	3,126	3,008	554	530	631	511
Jan 1 1958	3,295	3,196	590	537	657	544
Jan 1 1959	3,440	3,326	695	578	666	562
Jan 1 1960	3,527	3,398	838	688	673	573
Jan 1 1961	3,667	3,539	1,018	815	634	583
Jan 1 1962	3,911	3,693	1,128	960	654	563
Jan 1 1963	3,924	3,810	1,128	1,081	662	579
Jan 1 1964	4,039	3,937	1,249	1,146	661	582
Jan 1 1965	4,077	4,009	1,468	1,270	676	586
Jan 1 1966	4,129	4,049	1,657	1,446	702	596
Jan 1 1967	4,190	4,121	1,865	1,643	769	623
Jan 1 1968	4,249	4,156	2,004	1,753	818	644
Jan 1 1969	4,300	4,237	2,114	1,938	834	672
Jan 1 1970	4,344	4,269	2,651	2,476	1,038	872
Jan 1 1971	4,383	4,323	2,705	2,636	1,025	892
Jan 1 1972	4,411	4,355	2,971	2,783	1,004	905
Nov 30 1972	4,429	4,381	3,139	2,950	1,004	922

There are over 3400 FM stations in the U.S.A. They operate on one of the two hundred 200 kHz wide channels between 88.1 and 107.9 MHz. There are four classes of stations, which are differentiated according to permitted transmitter power and antenna height. Each class of station is provided a set of channels on which to operate. Directional antennas are not permitted. In effect, the FM spectrum is authorized on the basis of technical assumptions which facilitate administration. Each class of channels is permitted to operate on different frequencies. In order to avoid interference, co-channel and adjacent channel separation criteria are employed. These, coupled with transmitter power and antenna height limitations, dictate the number of permitted FM stations, regardless of how much spectrum engineering is accomplished.

Table 2.4 - Technical Characteristics of AM Stations

Class of Channel	Class of Station	Permissible Power (kW)	Signal-Intensity Contour of Area Protected from Objectionable Interferences (microvolts/meter) Day[1]	Signal-Intensity Contour of Area Protected from Objectionable Interferences (microvolts/meter) Night	Permissible Interfering Signal on Same Channel (microvolts/meter) Day[1]	Permissible Interfering Signal on Same Channel (microvolts/meter) Night[3]
Clear	I-A	50	Sc=100 Ac=500	Sc=500[2] Ac=500[1]	5	25
	I-B	10-50	Sc=100 Ac=500	Sc=500[2] Ac=500[1]	5	25
	II-A	0.25-50 day 10-50 night	500	500[1]	25	25
	II-B II-D	0.25-50	500	2500	25	125
Regional	III-A	1-5	500	2500[1]	25	125
	III-B	0.5-5 day 0.5-1 night	500	4000	25	200
Local	IV	0.1-1 day 0.1-0.25 night	500	not prescribed	25	not prescribed

Notes:
Sc-same channel, Ac-adjacent channel
[1]Ground wave
[2]50% sky wave
[3]10% sky wave

A similar authorization approach is utilized for both VHF and UHF television stations. There are over 900 such stations in the U.S.A. Co-channel and adjacent channel separation criteria, antenna heights, and power limitations determine the upper limit on the number and location of stations which may be authorized. All but about 12 of the possible VHF licenses have been granted; however, of the approximately 1200 possible UHF licenses, only about 350 have been granted.

2.2.2 Safety and Special Services

The Safety and Special Radio Services Bureau issues more licenses than any other. This results from the fact that most land, aeronautical, and maritime mobile uses of radio in the private sector come under its jurisdiction. Each mobile transmitter requires a license. Table 2.5 indicates the services for which this bureau processes licenses.

Table 2.5 - Safety and Special Radio Services*

Amateur and Disaster (Part 97)
- Amateur
- Disaster
- RACES

Aviation (Part 87)
- Aeronautical
- Aircraft
- Aviation Auxiliary
- Aviation Radionavigation Land
- Civil Air Patrol

Citizens (Part 95)
- Class A
- Class B
- Class C
- Class D

Industrial (Part 91)
- Business
- Forest Products
- Industrial Radiolocation
- Manufacturers
- Motion Picture
- Petroleum
- Power
- Relay Press
- Special Industrial
- Telephone Maintenance

Land Transportation (Part 93)
- Auto Emergency
- Interurban Passenger
- Interurban Property
- Railroad
- Taxicab
- Urban Passenger
- Urban Property

Maritime (Parts 81 and 83)
- Alaskan
- Coastal
- Marine Auxiliary
- Marine Radiolocation

Public Safety (Part 89)
- Fire
- Forestry Conservation
- Highway Maintenance
- Local Government
- Police
- Special Emergency
- State Guard

* Items in parentheses indicate those parts of the FCC Rules and Regulations which are applicable.

NOTE: Refer to Table 1.4 for complete listing of FCC Rules and Regulations.

2.2.2.1 Mobile Communications Services

The mobile communications services are perhaps most representative of the variety of spectrum management techniques used from an administrative standpoint. These services are accommodated in seven blocks of spectrum between 25 MHz and 866 MHz. Each of these blocks is further subdivided to one or more of the indicated services. This

is sometimes referred to as *block allocation.*

Because of the number of applicants for frequencies in these services, it is impossible for the FCC to provide a thorough check of a new application to determine the likelihood of harmful interference. It therefore enlists the assistance of various advisory groups, and requires potential licensees to consult with them. In this regard, the FCC Rules state:

> "A statement from a frequency advisory committee recommending specific frequencies which are available for assignment in accordance with the loading standards and mileage separations applicable to the specific radio service involved is required. The frequency advisory committee must be so organized that it is representative of all persons having access to the specific groups of frequencies involved".[5]

Each service, in addition to the above mentioned techniques, has certain technical restrictions affecting use of the spectrum, including power, antenna height, authorized bandwidth, and frequency.

The vast majority of spectrum utilized by land mobile services is licensed as detailed above. However, since 1973, development of the Regional Spectrum Management concept has been underway in the Chicago area. This project involves the application of spectrum engineering principles to the mobile services, and is described in more detail in Sec. 6.4.

2.2.2.2 Aeronautical Mobile Route (R) Service

The bands exclusively allocated worldwide for this service between 2850 and 18030 kHz for communications to and from commercial aircraft have been agreed upon by the International Telecommunication Union (ITU) convention as set forth in Appendix 27 of the Radio Regulations. Therefore, the bands so specified may not be modified for domestic use. Assignments made in the bands indicated in this plan must be accomplished in conformity with its provisions. This includes conforming to the Major World Air Route Area (MWARA) and Regional Domestic Air Route Area (RDARA) allotment plans.

2.2.2.3 Maritime Mobile Service

The obtaining of frequency assignments in the maritime mobile services is guided by the provisions of the International Radio Regulations. In particular, there are several international plans which specify the use of these bands; e.g., Appendices 15, 17, 18, and 25 (coastal telephone). These documents represent plans for the use of certain frequences for this service. A technique which is used in

this context is to specify the dates at which particular technical changes must be implemented. An example of this is indicated in Table 2.6.[1]

Table 2.6 - Dates for Implementing the Final Acts of the 1967 ITU Maritime WARC

Action Required	ITU Date	OTP Date	FCC Date
4-23 MHz. Coast stations cease use of DSB	1/1/72	1/1/72	1/1/72
4-23 MHz. No new installation of DSB on ships	1/1/72	1/1/72	1/1/72
1.6-4 MHz. No new installation of DSB on ships	1/1/73	1/1/72	1/1/72
VHF. All new equipment shall conform to 25 kHz standards	1/1/73	3/1/69	1/1/71
1.6-4 MHz. Coast stations cease use of DSB	1/1/75	1/1/75	1/1/72
1.6-4 MHz. Date 2170.5 kHz replaces 2182 kHz for selective calling	4/1/77	4/1/77	4/1/77
4-23 MHz. Coast stations cease use of A3H	1/1/78	1/1/74*	1/1/74*
4-23 MHz. Ship stations cease use of DSB	1/1/78	1/1/74	1/1/74
4-23 MHz. Ship stations cease use of A3H	1/1/78	1/1/74	1/1/74
1.6-4 MHz. Coast stations cease use of A3H except as provided in RR	1/1/82	1/1/77	1/1/77
1.6-4 MHz. Ship stations cease use of DSB and, except as provided in RR, cease use of A3H	1/1/82	1/1/77	1/1/77
VHF. 156.8 MHz guard band reduced to 156.7625-156.7875 and 156.8125-156.8375 MHz	1/1/83	8/68	8/68
VHF. All equipments shall conform to 25 kHz standards	1/1/83	1/1/74	1/1/74

* Coast stations required to communicate with foreign ships that use A3 emission may use A3H during the period 1/74 to 1/78.

2.2.3 Common Carrier Service

The licenses of principal concern are those for point-to-point microwave radio and satellite communications. The technical requirements which must be fulfilled in these services are specified in

Chapter 21 (Subpart I) and Chapter 25 of the FCC Rules and Regulations. The non-Government spectrum available for these services is indicated in Table 2.7.

Table 2.7 - Bands for Microwave Point-to-Point Communications Including Fixed Satellites (*)

2110-2130 MHz	17,700-19,700 MHz
2160-2180 MHz	21,200-22,000 MHz
*2500-2690 MHz	22,000-28,600 MHz
*3700-4200 MHz	27,000-29,000 MHz
*5925-6425 MHz	31,000-31,200 MHz
10,700-11,700 MHz	38,000-42,000 MHz
13,200-13,250 MHz	

The principal factors influencing the use of the spectrum include limitations on transmission power, microwave station separation distances, bandwidth and emission limitations, and channel loading. In addition to the spectrum management methods used by the FCC; the individual carriers, such as the American Telephone & Telegraph Company, employ spectrum management techniques in order to obtain full utilization of the spectrum bandwidths authorized.

2.2.3.1 Point-to-Point Microwave Systems

Many factors go into the determination of a frequency plan for a microwave system, preliminary to the request for a license. Fig. 2.2-(a) shows the typical interference considerations in a microwave relay system. Frequency plans such as those in Fig. 2.2(b) are utilized.[4]

2.2.3.2 Satellite Systems

As is apparent from Table 2.7, microwave point-to-point systems and fixed satellite systems share the same frequency bands. This is made possible by the generally narrow beams used by these systems, and the resulting orthogonality of operation. Nonetheless, authorization to operate satellite systems in the non-government fixed satellite bands is predicated on adherance to certain limitations. These include power flux density (as a function of elevation angle) and effective radiated power (ERP) of the earth stations. In addition, the FCC rules require interference coordination procedures with other earth stations and terrestrial stations in the same band. The interference paths, to which this coordination is applied, are indicated in Fig. 2.3.

Sections VII, VIII, and IX of Article 7 of the ITU Radio Regulations specify certain conditions for the operation of satellites in shared bands. No frequency assignment is granted unless these conditions are met. The conditions apply to the following:

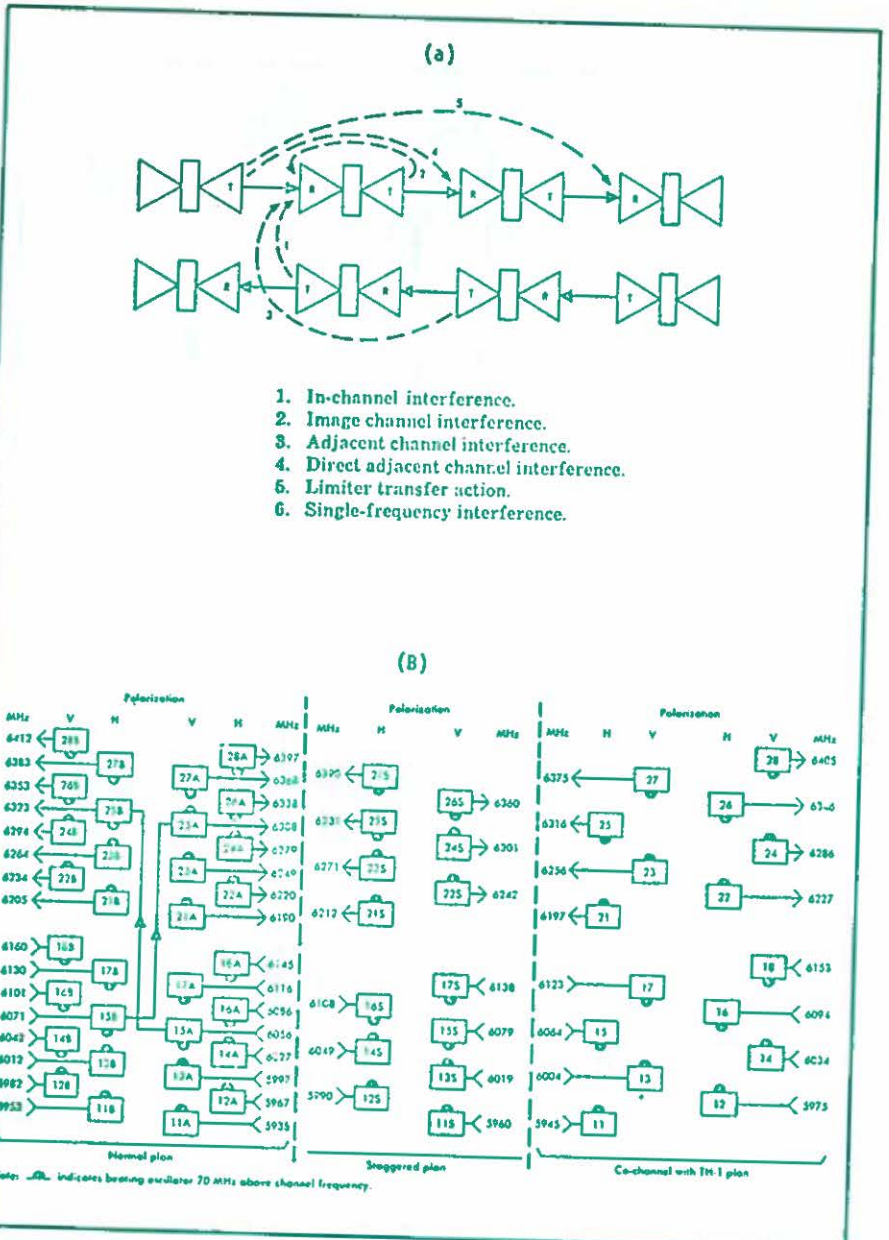


Figure 2.2 - Microwave Frequency Plans and Interference Considerations

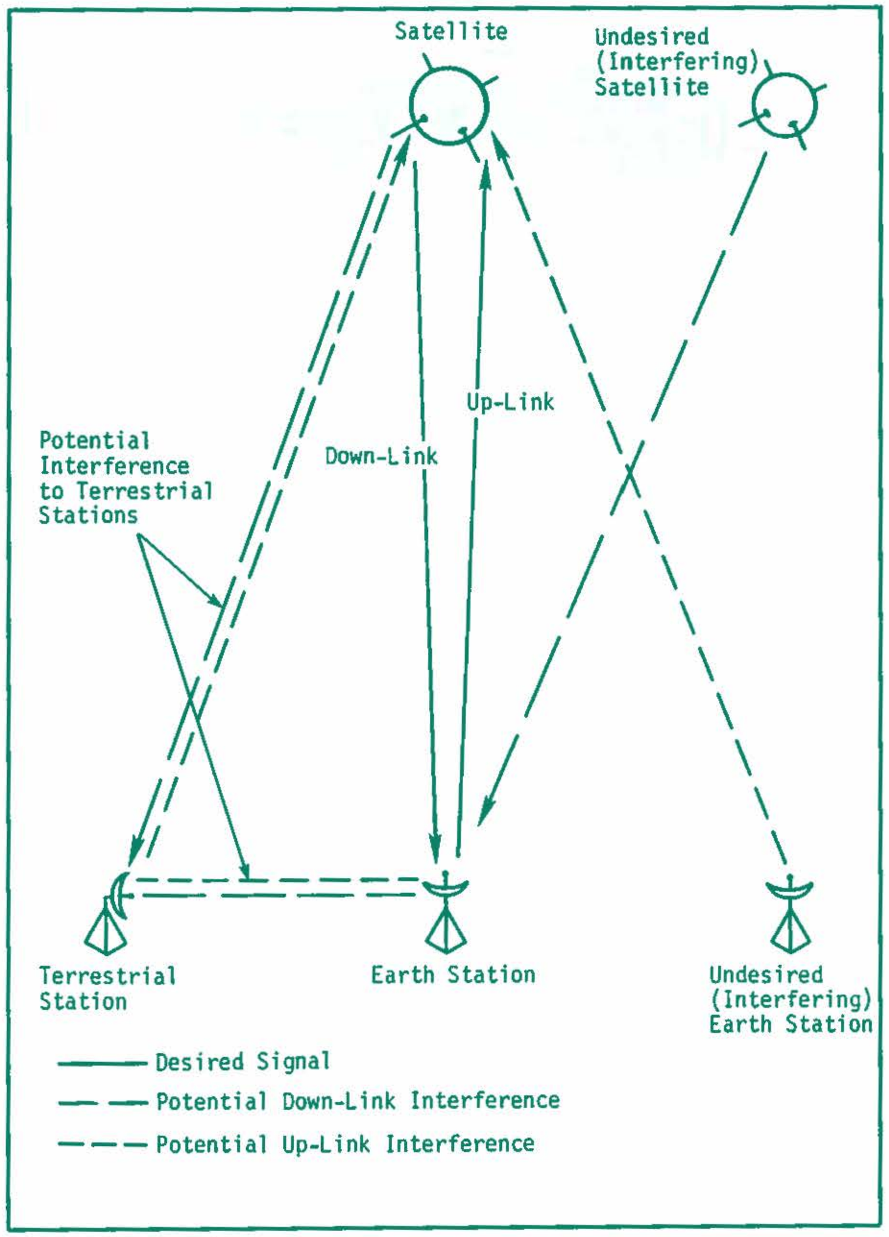


Figure 2.3 - Relationship of Sources of Potential Interference.

- Control of emissions from space stations;
- Power and direction of maximum radiation of stations in the fixed or mobile service in certain bands shared with stations in the space radiocommunication services;
- Selection of sites and frequencies for earth and terrestrial stations in the bands above 1 GHz shared with equal rights by terrestrial radiocommunication and space radiocommunication services;
- Power and direction of maximum radiation of earth stations in certain bands shared with stations in the fixed or mobile services;
- Power flux density limits at the earth's surface from space stations;
- Control of interference between geostationary satellite systems and non-synchronous inclined orbit satellite systems;
- Station keeping of space stations;
- Pointing accuracy of antennas on geostationary satellites.

2.3 NATIONAL AND INTERNATIONAL DATA BASES

Effective utilization of data bases has become one of the most important tools in spectrum management. Before the establishing of the Government Master File (GMF) in the United States, data bases on the use of the spectrum were kept in a somewhat unorganized fashion by a variety of organizations having a variety of information.

2.3.1 Frequency Lists

As of 1976, in the U.S. Federal Government, there is a single *Government Master File* which contains a list of all frequencies to which Federal Government radio stations have been assigned. Similarily, the FCC and the ITU each maintain lists of frequencies which have been licensed and notified, respectively.

In the first instance, the incorporation of a frequency in one of these three lists indicates that it has achieved authorization to operate domestically and/or internationally. This means that such a station is entitled to protection from interference, consistent with the technical description of the authorization.

2.3.2 The ITU International Frequency List

Table 2.8 is an excerpt from the International Radio Regulations which states what is indicated in the International Frequency List (IFL).

Table 2.8 - List I. The International Frequency List

This list shall contain:

(a) particulars of frequency assignments recorded in the Master International Frequency Register. These particulars shall include the data enumerated in Appendix 9;

(b) the frequencies (e.g., 500 kc/s or 2 182 kc/s) prescribed by these Regulations for common use by certain services, including frequencies specified in Appendices 15, 17, and 18;

(c) the allotments in the Allotment Plans included in Appendices 25, 26, and 27.

An indication of the use of the frequencies and allotments in Nos. 792 and 793 shall be included in the entries concerned.[9]

Frequency assignments in the International Frequency List shall be arranged in numerical ascending order of the frequencies assigned.

The International Frequency List above 28 Mc/s shall be in four separate parts as follows:

(a) frequency assignments in bands between 28 and 50 Mc/s, excluding broadcasting stations;

(b) frequency assignments in Region 1 in the bands between 50 and 40,000 Mc/s, and frequency assignments to broadcasting stations in Region 1 in the bands between 28 and 50 Mc/s;

(c) frequency assignments in Region 2 in the bands between 50 and 40,000 Mc/s;

(d) frequency assignments in Region 3 in the bands between 50 and 40,000 Mc/s, and frequency assignments to broadcasting stations in Region 3 in the bands between 28 and 50 Mc/s.

2.3.3 Non-Government Master File

The Non-Government Master File (NGMF)[3] is a list of licenses made to non-Federal Government users of the electromagnetic spectrum within the United States and its possessions. It contains no receiver data nor does it include the Amateur and Citizens' Radio Services licenses. Its contents indicate technical and administrative data applicable to non-Federal Government frequency assignments and radio stations.

2.3.4 Government Master File

The Government Master File (GMF) is the basic data base of radio frequency assignment of federal government radio stations located within the United States and its possessions. It does not normally include information on U.S. radio stations located in other countries, which must operate in conformance with the regulations of the host country.

The GMF provides specific information on location or area of operation, and some of the electromagnetic characteristics of the transmitters and receivers associated with each government frequency assignment. The contents of the individual records are normally updated on a monthly basis. These data include:

1. OTP-authorized frequency assignments to U.S. Government radio stations located within the United States and its possessions.

2. OTP-authorized frequency assignments to U.S. Government and non-Government radio stations located in the Trust Territory of the Pacific Islands. (Authorized by arrangement pursuant to footnote to Sec. 9.1.1, OTP Manual of Regulations and Procedures for Radio Frequency Management).

3. Frequency assignments used by U.S. Government radio stations located outside the United States and its possessions, and which could cause harmful interference to stations located within the United States and its possessions.

4. FCC-authorized frequency assignments to non-Government stations located within the U.S. and Possessions in the bands 200-415 kHz, 75 MHz, 108.000-121.975 MHz, 123.575-128.825 MHz, 132.025-136.000 MHz, 225.0399.9 MHz, 978-1020 MHz, 1030 MHz, 1157-1213 MHz, 1215-1400 MHz, 2700-2900 MHz, 5000-5250 MHz, 9000-9200 MHz, and 15.4-15.7 GHz.

5. FCC-authorized frequency assignments to non-Government radio stations on U.S. Government frequencies:

(a) for the Alaskan Communications System;
(b) for the Navajo Communications Company;
(c) for the Department of Health, Education and Welfare *Space Technology Applied to Rural Papago Advance*

Health Care Project.

There are over 126,000 assignment listings. This data base may be used to obtain: the listings of the entire data base, or portions thereof; the numerical counts of entries having specified characteristics; or geographical data plots. In contrast to a license, a single assignment can authorize the use of as many as 1,000 Government Radio Stations.

2.3.5 Other Considerations

There are a variety of auxiliary data bases which are useful spectrum management tools. These include lists of propagation models, equipments, and descriptions of electromagnetic compatibility models.

The frequency management data base, while of greatest importance in the operational aspects of frequency management, is also important to the planning and technical aspects.

At the time of an international conference, it is important that the IFL reflect up-to-date listings; so as to provide a certain measure of usage. Otherwise, there may be no justification for retaining a particular allocation.

The frequency management data base is a tool in formulating spectrum standards as well, because it provides a means of determining required technical boundary conditions to insure against adverse interference.

2.4 USAGE DETERMINATION METHODS

This section will describe the various techniques used primarily within the U.S. federal government to obtain and utilize information on how the radio spectrum is actually being used. The techniques to be described include reporting, on-sight inspection, and electronic measuring/monitoring. The last is covered more extensively in Chap. 5.

2.4.1 Usage Reporting

Specific frequency usage is required to be reported for certain government frequencies. The express purpose of such an activity is to ensure taht the limited frequency resources are deployed in the most efficient fashion. It is applied in those parts of the spectrum where there is a particularly critical need for channels. The OTP Manual defines spectrum usage as: "The on-the-air radiation time for any particular frequency, i.e., from time of first use each day to time of last use each day, less any intervals of non-radiation".[1]

There are basically two such programs in the federal government-one for HF(4-30 MHz) and one for VHF (certain government bands between 30 and 420 MHz). In general, federal government users, in the former part of the spectrum, are required to provide the information indicated in Table 2.9 on a quarterly basis. Reporting, by federal users in the latter part of the spectrum, requires annual submittal of the information specified in Table 2.10.

The license renewal and enforcement processes account for the FCC's approach to usage reporting. The radio services under FCC jurisdiction are required to renew their licenses at various intervals. This process, particularly in the broadcast services, serves the purpose of ensuring that spectrum is being effectively used. However, in some services, such as the mobile services, it is difficult to maintain sufficiently accurate records to make certain that this process works.

2.4.2 Five Year Review

The U.S. Federal Government maintains a five year review program as an additional technique. Under this procedure, each federal government frequency assignment is reviewed once every five years in the fashion specified in Table 2.11.[1]

The objectives of this program are: (1) to ensure that frequency assignments are in current use, and are correctly reflected in the frequency list of Frequency Assignments to Government Radio Stations; (2) to ensure that frequency assignments are required for continued operations for the purposes stated in their justifications; and (3) to ensure that frequency assignments are still qualified for authorization under the provisions of the regulations contained in the OTP Manual.

2.4.3 Measuring/Monitoring

The third major technique used for obtaining information on how the spectrum is actually being used is through real-time measurement/monitoring in the field.

The U.S. Federal Government initiated such a program in 1973 through the implementation of a van-mounted Radio Spectrum Measurement System (RSMS) operated by the Department of Commerce under the direction of OTP. This facility is used to: (1) determine whether radio installations operated by the federal government are utilizing authorized frequencies, and are operating in accordance with applicable regulations; (2) provide information to help determine whether additional uses can be made in a particular band at a particular location; and (3) provide information to prevent or resolve cases of interference between two or more users. Fig. 2.4 [2] shows how occupancy data can be used to determine alternative channel usage policies. The solid lines indicate

Table 2.9 - Usage Information Below 30 MHz

1. The frequency as indicated in the list of Frequency Assignments to Government Radio Stations.

2. The applicable Agency Serial Number (SER).

3. A number/letter combination to indicate the year and semi-annual period. Use the last digit of the year for the number and S or W (summer or winter) for the season. Examples: 3S for the summer (April - September) of 1973; 3W for the winter (October 1973 - March 1974) of 1973.

4. The total number of hours of frequency usage during the period under the authority of the assignment concerned. In the case of more than one station operating under the authority of a single frequency assignment, it is recognized that the number of hours reported may exceed the actual number of hours in half a year. In the case of an assignment with multiple receiving points, the figure reported shall be the combined frequency usage to all the receiving points.

Four digits or three digits and one letter shall be used in reporting the number of hours. For usage between 0 and 9999, show the actual number of hours. For 10000 hours or more, show the nearest thousand hours suffixed by the letter K. Examples (note leading zeros): 0015 for 15 hours, 1293 for 1293 hours, 016K for 16125 hours.

5. A single letter to indicate, when applicable, the reason why there has been less than 20 hours usage during the period. Use the following letters for the reasons shown:

A - Emergency or backup

B - No equipment or incomplete equipment

C - Equipment breakdown

D - Frequency needed for other requirements

E - Low number of field operations held

F - Low traffic volume

G - Recently authorized frequency

H - Disruptive interference

J - Propagation would not support communications required

L - Operations in accordance with an international plan or schedule

N - Operations on which a guard is maintained pursuant to international obligations.

Table 2.10 - Usage Information for Assignments Above 30 MHz[1]

1. The frequency as indicated in the list of Frequency Assignments to Government Radio Stations.

2. The applicable Agency Serial Number (SER).

3. The system name, if reporting by system.

4. A two-digit number to indicate the calendar year.

5. Annual on-the-air hours for all transmitters authorized by individual assignment.*

* Agencies may, at their option, report either a specific number of hours or one of the following ranges of hours:

Range of Hours	Figure to Report
0	0
1 - 50	50
51 - 999	Nearest 100
1000 and above	Nearest 1000

Zero usage shall be reported as zero. Zero shall not be used to report unknown usage; e.g., when no report is received from the field.

Agencies may, at their option, determine the number of hours by an annual survey of the number of on-ther-air hours during a period of not less than two weeks, multiplied by a figure to equal the number of annual hours.

In the U.S. Federal Government there are two principal purposes of usage information:

1. to insure that the assigned frequencies are actually being used;

2. to provide a basis for determining assignment patters.

Within the FCC, the emphasis is on the latter of these two objectives. It should be remembered that many government spectrum applications are of a critical nature. Availability - on short notice - is the principal requirement of clear frequencies, rather than quantity of use.

actual distribution of usage of land mobile frequencies in different services in two major metropolitan areas; and the dotted lines show criteria which could cause more equitable distribution of usage and a more efficient use of spectrum. (Also see Chap. 6).

Table 2.11[1] - Five Year Review Procedure

1. The purpose of this procedure is to achieve the objectives mentioned in Sec. 8.2.6.[1] Normally, this will be effected by reviewing, within a given year, all assignments that were last reviewed five years earlier.

2. The date of the last review of an assignment can be determined by the entry in the REVISION DATE (RVD) field, or the REVIEW YEAR (RYR) field (RYR is a portion of the RELATED ACTION field).

3. Within five years of the latter of the two dates, the FAS Representative concerned, will determine for each of his agency's assignments:

   a) whether an assignment is essential to meet the agency's requirements;
   b) if so, whether other existing assignments will meet the requirements;
   c) if not, whether the justification for and description of the assignment under review, as previously given, are still accurate;
   d) if so, whether the assignment is completely up-to-date.

4. An assignment is completely up-to-date if it contains, in the proper fields, all of the particulars required by this Manual.

5. The FAS Representative will delete those assignments that are not qualified for retention under 3a and 3b above, and modify those that are not completely up-to-date. If he finds assignments that are qualified for retention and completely up-to-date, he may request the FAS Chairman, by memorandum, to have the assignments amended by inserting in the REVIEW YEAR field the last two digits of the current year.

6. The FAS Chairman will review the assignments, and, if any further action appears to be necessary, he will inform the FAS Representative. If no further action appears necessary, he will have entered in the REVIEW YEAR field of these assignments the last two digits of the year in which the review occurred; i.e., 78 if the review occurred in 1978. This will require no action by the FAS Representative. The date will be printed in the list of Frequency Assignments to Government Radio Stations.

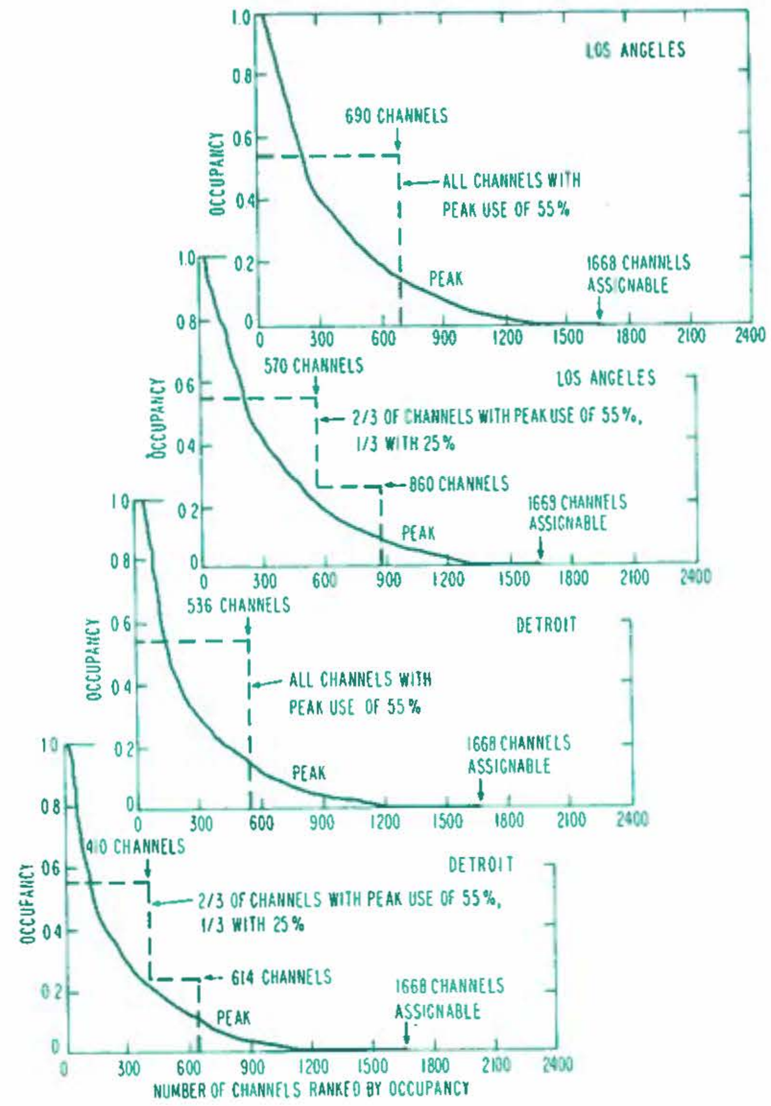


Figure 2.4 - Equal-Channel-Occupancy Criteria-55% and 55%/25%.

2.5 INSPECTION AND ENFORCEMENT

Compliance is concerned with unauthorized or improper transmissions. The operational techniques used to ensure compliance differ markedly between the FCC and the OTP.

In the Federal Government, most enforcement and compliance actions are carried out at the regional or agency level. The principal enforcement activities carried out by OTP are accomplished through on-site inspection and use of the RSMS. The on-site inspections are primarily concerned with determining the extent to which individual agencies have either discontinued transmissions for which they were authorized, or are using unauthorized transmissions.

The RSMS may also be used to perform these enforcement functions in its areas of operation, but it is more likely to be used in ascertaining the adherence of a particular transmission to technical criteria specified in the OTP Manual. An example of this is illustrated in Fig. 2.5, which shows the spectrum signature of a radar, compared to the signature of the OTP Spectrum Engineering Criteria.

Most of the enforcement is actually carried out within the individual agencies or regional coordinating organizations. It is, of course, in their respective interest to carry it out in order to ensure the integrity of their individual operations.

The enforcement function of the FCC is primarily carried out in the 24 districts of its Field Engineering Bureau. The basic task of the local units is to respond to complaints of interference from public users. To the extent that interferences are caused by deviations from specified rules and regulations, the FCC and its field officers have the authority to rectify the situation, including the taking of offending parties to court and the levying of fines. The nature of these enforcement activities is specified in the responsibilities of the Enforcement Division of the Field Operations Bureau. These are described as follows:

a) To make recommendations concerning field enforcement policies, programs, objectives, priorities and resource allocations; to recommend legislation and rules revisions which will facilitate field enforcement activities; to formulate budget requirements for approved programs; and to develop operational plans to execute programs within allocated resources.

b) To direct the enforcement monitoring program, coordinate enforcement monitoring activities among the various fixed and mobile monitoring facilities; to operate the bureau's fixed monitoring and direction finding networks; to coordinate international monitoring and direction finding

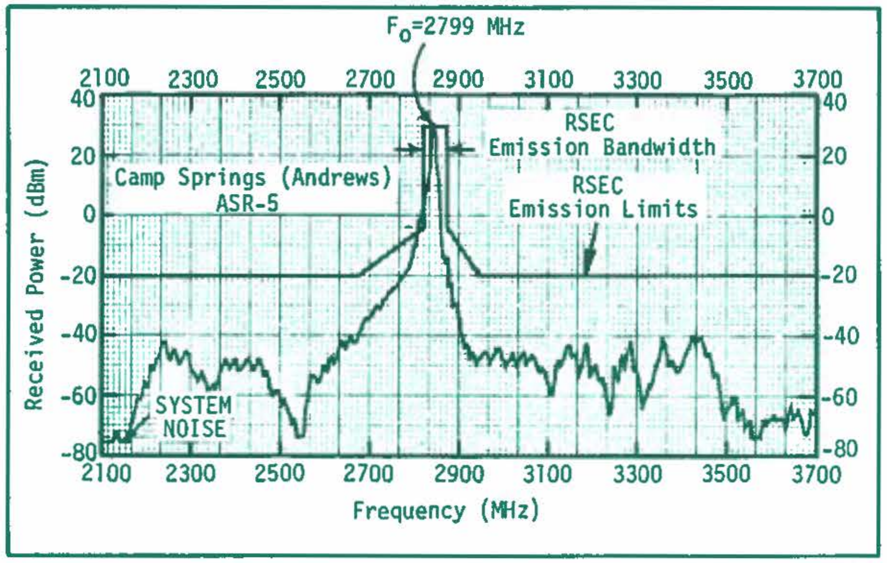


Figure 2.5 - Measured Radiated Emission Spectra and Calculated RSEC Allowable Emission Bandwidth and Permissible Emission Limits

activities; to operate the Bureau's Communications Center to provide rapid contact with all enforcement facilities; and to coordinate the operation of all types of communications facilities used by Field Enforcement Installations.

c) To direct the station inspection program; to develop and implement procedures and field directives for technical inspections and measurements for all categories of radio stations and wire facilities; and to coordinate the inspection activities of the field enforcement staff with the technical and compliance staffs of the bureaus responsible for the services covered by the inspection program.

d) To direct the Bureau's investigative program; to develop and implement procedures and field directives for conducting investigations: (i.e., specialized enforcement teams, mobile direction finding and measurement); to provide expert technical witnesses in investigative cases resulting in administrative hearings and/or trials in Federal Courts; to coordinate with legal and technical staffs of other bureaus and offices concerning on-going case assignments; to prepare procedures for resolving complaints regarding interference to electronic home entertainment equipment without on-site inquiry.

e) To direct issuance of discrepency notifications; to direct issuance of Notices of Apparent Liability in the Safety and Special Radio Services; to conduct enforcement case work, and to prepare referrals to the Violations Division; to re-recommend actions to expedite the imposition of desired sanctions; to keep the Violations Division advised of pro gress on open cases assigned to the field.

2.6 MANUAL OF REGULATIONS FOR USE OF THE SPECTRUM IN THE U.S. FEDERAL GOVERNMENT

The promulgation of and adherence to the Manual of Regulations, for the use of the spectrum in the federal government, is one of the most powerful techniques for the effective use of the radio spectrum. It is issued by the Office of Telecommunications Policy, and is specifically designed to cover its frequency management responsibilities.

The Manual is a basic authority for national frequency coordination and assignment. It has ten chapters and seven appendices. Table 2.12 gives an outline of its contents.

Table 2.12 - Contents of Manual of Regulations

Chapter 1	- Authority and Organization
Chapter 2	- Telecommunications Policy
Chapter 3	- International Matters
Chapter 4	- Allocations, Allotments, and Plans
Chapter 5	- Technical Standards, Requirements, and Objectives
Chapter 6	- Definitions and Particulars of Assignments
Chapter 7	- Authorized Frequency Usage
Chapter 8	- Procedures and Principles for the Assignment and Coordination of Frequencies
Chapter 9	- Preparation of Applications for Frequency Assignment Action
Chapter 10	- Processing of Applications for Frequency Assignment Action
Annex A	- Record Notes
Annex B	- Data and Procedures for Assessing Interactions among Stations
Annex C	- Procedures for Reporting of Frequency Usage Information
Annex D	- Procedure for Field Level Selection and Coordination of Radio Frequencies
Annex E	- Notification of Laser Operations for Other than Telecommunication Purposes
Annex F	- Five Year Review Procedure
Annex G	- Abbreviations

Many of the parts of the manual are treated in other sections of this book. Following are discussions of those matters not addressed in any significant detail elsewhere.

a) Authority and Policy - The substance of these parts is addressed in Chapters 1 and 2.

b) International Matters - Of particular note is sec. 3.4 of

this chapter which sets forth the basis for Canadian Coordination. It consists of a technical Annex and four separate coordination arrangements. These arrangements indicate the bands and cognizant agencies responsible for coordination in the respective countries, and the specification of information to be exchanged with respect to specified aviation bands, fixed installation radars, and certain frequency bands above 30 MHz.

● Allocations, Allotments, and Plans - This chapter reflects the national agreements which have been reached between the FCC and OTP in regard to which frequency bands are to be exclusively government, exclusively non-government, and shared in the United States; as well as the associated International Allocation. Fig. 2.6 is an illustration of these allocation agreements. Also included is a set of explanatory notes. There are four categories of notes:

1. G - applicable to government only,
2. US - applicable to government and non-government,
3. NG - applicable to non-government only, and
4. International - applicable in ITU Region 2.

● Standards - The content of this chapter is elaborated in more detail in Chap. 6.

● Definitions - This chapter contains an extensive list of definitions which apply in particular frequency bands.

● Authorized Frequency Usage - This chapter sets forth the conditions under which certain types of government use of electromagnetic spectrum may be authorized. These include "Emergency, Disaster or War Communications, Manned Spacecraft, Incidental Radiation Devices, Restricted Radiation Devices (low-power), ISM Equipment, Experimental Stations, Tactical and Training (Military), and Test Ranges.

● Procedures - This section includes the basic coordination agreement between OTP and FCC, and sets forth a number of specialized coordination procedures for particular bands. Included in this chapter is the procedure for systems review which is discussed in depth in Chap. 4, and is one of the newest, most powerful techniques for management of the spectrum.

● Applications - This chapter provides detailed instructions with regard to the preparation of an application to obtain an assignment.

● Processing of Assignments - The several sections of this chapter describe the steps to take when an assignment does not for one reason or another follow the normal processing procedures.

● Annexes - The annexes address the special subjects as indicated in Table 2.12.

606-790 BROADCASTING 329 330 330A 331 332 332A		610-890 FIXED MOBILE BROADCASTING 330B 332 332A 338 339	806-902	NG US36 US116		LAND MOBILE NG30 NG43 NG63 NG65	806-881 Domestic public 881-902 (non-common carrier)
790-890 FIXED BROADCASTING 329 331 333 334							
890-942 FIXED BROADCASTING Radiolocation 329 331 333 339A	890-942 FIXED RADIOLOCATION 339A 340	890-942 FIXED MOBILE BROADCASTING Radiolocation 339 339A	902-928 (ISM 915 ± 13 MHz)	G US36 US115 US215 US218	RADIOLOCATION G11 G59		
942-960 FIXED BROADCASTING 329 331 333 339A	942-960 FIXED 339A	942-960 FIXED MOBILE BROADCASTING 338 339 339A	928-947	NG US36 US116 US215		LAND MOBILE NG64	(non-common carrier)
			947-960	NG		FIXED NG9 NG10 NG40 NG58	
960-1215	AERONAUTICAL RADIONAVIGATION 341		960-1215	G, NG 341	AERONAUTICAL RADIONAVIGATION	AERONAUTICAL RADIONAVIGATION	
1215-1300	RADIOLOCATION Amateur 342 343 344 345		1215-1300	G, NG US34	RADIOLOCATION G12 G55 G56 G111	Amateur	
1300-1350	AERONAUTICAL RADIONAVIGATION 346 Radiolocation 347 348		1300-1350	G, NG 346	AERONAUTICAL RADIONAVIGATION Radiolocation G2	AERONAUTICAL RADIONAVIGATION	

KEY:
G = Government Allocation   US- = Special Provision For Use of Band in U.S.
NG = Non-Government Allocation

Figure 2.6 - Example of OTP Manual Allocation Table.

2.7 REFERENCES

1. Manual of Regulations and Procedures for Radio Frequency Management, Office Telecommunications Policy (OTP); 1975.

2. A Spectrum Measurement/Monitoring Capability for the Federal Government; Stanford Research Institute, Contract Report for OTP, May 1971.

3. An Automated Data Base for the Federal Government; HRB-Singer Contract Report for OTM, Vol. I & II; 1968.

4. Communications Systems Engineering; Bell Laboratories; 1972.

5. FCC Rules and Regulations.

6. Reference Data for Radio Engineers; ITT, Fifth Edition.

7. Broadcasting Yearbook; Broadcasting Publications, Inc.; 1973.

8. Managing the Use of Radio; OTP; 1975.

9. International Radio Regulations, International Telecommunications Union; Geneva Switzerland.

CHAPTER 3

PLANNING TECHNIQUES

This chapter is concerned with those techniques which either implicitly or explicitly deal with planning the use of the radio spectrum. This chapter will describe the ways in which allocation conferences, new technology, FCC Notices of Inquiry, advanced notification of systems, and periodic assessment of overall band usage serve as planning mechanisms. Most of these techniques have been developed within the last five years. They have been necessitated by the need to obtain more intensive utilization of the radio spectrum.

The objective of spectrum planning is to provide for future spectrum needs. The basic guide for the use of the spectrum is the allocation tables. World Administrative Radio Conferences are the ways and means by which these tables are modified, and provide the basic forcing functions for planning. These forcing functions include spectrum congestion, new requirements, and advances in technology.

3.1 WORLD ADMINISTRATIVE RADIO CONFERENCES

The preparation for World Administrative Radio Conferences provides a highly important opportunity for exercising methods of frequency allocation. A radio frequency allocation is characterized by a bandwidth and a service indication. Appendix 1 shows the structure of the International Radio Regulations.

The width of the allocation, nature of services, spectrum region(s), and associated technical criteria are determined during the course of a WARC. As indicated in Chap. 1, these conferences have a history of over fifty years. The modern era of radio conferences began at the 1947 Radio Conference held in Atlantic City. This was a General Radio Conference. The next General Radio Conference was held in 1959 and lasted four and one half months. Subsequently, only specialized conferences have been held, i.e., conferences in which only one major service type is treated, - such as Aeronautical, Maritime, or Space. Because these specialized conferences have not been able to address all allocation requirements, another World Administrative Radio Conference is scheduled

for 1979.

The results of these international radio conferences are considered international treaties, and as such, have the status of international law. They must be advised and consented on by the Senate and signed by the President. The results are then implemented domestically by the FCC and the OTP, and provide a basic guide with respect to other domestic allocations of spectrum.

The WARC's make the biggest impact on domestic planning of the radio spectrum in the years preceding the conference. During these years, the existing allocation structure is examined in light of foreseen needs. Preparation for the Space WARC held in the summer of 1971 commenced during the summer of 1969, a full three years before the conference. Preparation for the Radio Conference to be held in 1979 has been under way since the fall of 1974.

Preparation for a WARC forces spectrum users in both the government and non-government sectors to think in terms of potential requirements; realizing that another chance to restructure the allocation table may not occur for over ten years. Inevitably, there are requirements that cannot be met in available bandwidth; or for which international recognition cannot be achieved because of conflicts elsewhere in the world. The final proposals of the United States represent an agreed position between the FCC and the OTP with respect to which new bands will be government and which will be non-government, and to which will be shared.

Figures 3.1(a) and (b) indicate allocations in the 7.9 to 8.5 GHz range. If a service is shown in bold face, it is primary; if italicized, secondary. The latter must protect the former. In addition, there may be footnotes to indicate specialized usage. Other aspects of the Radio Regulations may specify technical conditions which must prevail within a particular allocation.

Figures 3.1(a) and (b) also illustrate the transformations which take place in the allocation tables to accommodate new requirements. Fig. 3.1(a) indicates the allocation breakdown of this spectrum before the 1971 Space WARC. Fig. 3.1(b) shows the same spectrum after the WARC-ST. The changes include the following:

a) there are now six allocations instead of four;

b) the Communications Satellite Service is now the Fixed Satellite Service (the new definition excludes the use of mobile terminals);

c) two new services, Earth Exploration and Meteorological Satellites, have been added to certain parts of the spectrum on a primary shared basis.

(a)
Before 1971
GHz

Region 1	Region 2	Region 3
7,900-7,975	Fixed Mobile Communication-Satellite (Earth-to-satellite) 392*	
7,975-8,025	Communication-Satellite (Earth-to-satellite) 392A 392C 392H	
8,025-8,400	Fixed Mobile Communication-Satellite (Earth-to-Satellite) 392A 394 394B	
8,400-8,500 Fixed Mobile Space Research 394A 394D	8,400-8,500 Space Research 394C	8,400-8,500 Fixed Mobile Space Research 394A 394D

* Alphanumerics refer to the notes which accompany the complete set of tables.

(b)
After 1971
GHz

Region 1	Region 2	Region 3
7,900-7,975	Fixed Fixed-Satellite (Earth-to-space) Mobile	
7,975-8,025	Fixed-Satellite (Earth-to-space) 392H	
8,025-8,175 Fixed Fixed-Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth) 394B	8,025-8,175 Earth Exploration-Satellite (Space-to-Earth) Fixed Fixed-Satellite (Earth-to-space) Mobile	8,025-8,175 Fixed Fixed-Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth)
8,175-8,215 Fixed Fixed-Satellite (Earth-to-space) Meteorological Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth) 394B	8,175-8,215 Earth Exploration-Satellite (Space-to-Earth) Fixed Fixed-Satellite ((Earth-to-space) Meteorological-Satellite (Earth-to-space) Mobile	8,175-8,215 Fixed Fixed-Satellite (Earth-to-space) Meteorological-Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth
8,215-8,400 Fixed Fixed-Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth) 394 394B	8,215-8,400 Earth Exploration-Satellite (Space-to-Earth) Fixed Fixed-Satellite (Earth-to-space) Mobile	8,215-8,400 Fixed Fixed-Satellite (Earth-to-space) Mobile Earth Exploration-Satellite (Space-to-Earth) 394
8,400-8,500	Fixed Mobile Space Research (Space-to-Earth) 394A 394D	

Figure 3.1 - 7.9-8.5 GHz Spectrum Range Before and After 1971 WARC-ST

In the United States these bands are allocated to the government. It is now possible to provide considerably more utilization of these bands because of this allocation conference.

Table 3.1 sets forth the U.S. objectives for the 7.9 to 8.5 GHz range and the outcome of the 1971 Space WARC. As is evident, the U.S. was able to achieve the majority of its objectives. The results also indicate the domestic use of the new spectrum obtained. The specific amount of spectrum obtained in each of the services is indicated in Table 3.2 for allocations below 40 GHz. In total, this WARC made available in one form or another over 15,000 MHz of spectrum for new space radio services. The impact of such a conference will be felt for a long time to come.

3.2 SYSTEMS REVIEW PROCEDURE

A procedural result of the WARC-ST was the development of a technique called *Advance Notification*, the specifics of which are contained in Article 9A of the Radio Regulations. The rationale and details of the procedure are discussed in Sec. 3.4. This procedure calls for the provision of characteristics of space telecommunication systems to other ITU member countries for the purpose of coordination. Prior to this WARC, the United States did not have a methodology for systematically obtaining such information. The need for such information gave rise to the *Procedures for the Review of Telecommunication Systems for Frequency Availability and Electromagnetic Compatibility*, contained in Sec. 8.3 of the OTP Manual.

The purpose of this planning technique is to determine, at as early a stage as possible, the problems which a new communication-electronic system may encounter or cause in operating in its intended electromagnetic environment. More specifically this technique is required:

> "...to assist Government agencies in taking all reasonable measures to insure that...(new systems) will neither cause nor receive harmful interference to or from authorized users, and to support the OTP and the IRAC in the management of the radio spectrum resource for the satisfaction of Government requirements, and in the national interest, the procedures provide for the review of new Government telecommunication systems and subsystems by the Spectrum Planning Subcommittee (SPS) at a number of stages of their evolution prior to the assignment of frequencies".[1]

This procedure has been in effect since the spring of 1972. There are four stages at which a new system should be brought into the SPS for review. These are described in Table 3.3.

The information provided on the systems at each stage is subjected to analysis to determine compatibility with other systems. In general

Table 3.1 - Results of 1971, WARC-ST

Service	Objectives	Results (G,NG,S)
Broadcasting Satellite	Accommodate in FM and UHF TV Bands subject to agreement among Administrations concerned	UHF band agreement-NG
	Accommodate in 11.7-12.26 GHz	Agreed-NG
	Include "Community Reception" in definition	Agreed-NG
Radio Astronomy	Remove sharing with Standard Frequency Bands-30MHz	Agreed
	Obtain 20kHz<30MHz	Agreed
	Primary status for 38, 406, 1160 MHz	Only 406 & 1660
	400 MHz between 17.7-30 GHz	Agreed
	Allocation for Water Vapor (22GHz) and line frequencies above 40GHz	Agreed
	Allocation on Far Side of Moon	Resolution
Communication Satellite	More Shared Spectrum Below 17GHz	Agreed-G/NG
	Shared and Exclusive Bands Between 17-40GHz	Agreed-G/NG
	Allocation Above 40GHz	Agreed-G/NG
	Provide for Intersatellite Relay	Agreed-G/NG
	Provide for Transmission of TV Program Material	Agreed-G/NG
Distribution Satellite	Define New Service Provide Allocations for this Serv.	Included in NG B/C Sat. Serv.
Meteorological Satellite	Additional 10MHz between 1160-1690 MHz	Agreed-G
	More Shared bands between 400-8000 MHz	Agreed-G
Earth Exploration	Define New Service	Agreed-G
	Provide Allocations for this Serv.	Agreed-G
Amateur	Use of Space techniques in all Amateur bands	Agreed only in exclusive amateur bands
Space Research	Change telemetering to Space-to-Earth Operation	Agreed-G
	New Allocation for Space Operations	Agreed-G

Table 3.1 - (Continued)

Service	Objectives	Results (G,NG,S)
	Provide for measuring systems	Region 2 and certain areas in Regions 1 & 3
	Passive Radiometer Measurement >40 GHz	Agreed
Aeronautical Mobile	Use of Space Techniques in band 1535-1660 MHz	Agreed-G/S
	Allocation above 40 GHz	Agreed-S
Maritime Mobile	Use of Space techniques in 160 and 1600 MHz	Agreed-S
	Allocations above 40 GHz	Agreed-S
Mobile	Use of Space Techniques in bands 235-328.6 and 335.4-399.9 MHz	240-328.6/ 335.4-399.4MHz
	Provide for Emergency in 400 MHz band	Agreed
STD Frequency	Allocations in 400 MHz band	Agreed

G = Government
NG = Non-Government
S = Shared

these analyses are concerned with:

a) compliance with prevailing standards and sharing criteria;

b) predicted degree of EMC with the environment;

c) relative efficiency in the use of the radio spectrum by the proposed system; and

d) system modifications or alternatives, including modifications to stations already operating in the band(s) in question.

The information required to be filed by an agency for the system review may be found in the OTP Manual. The information provided is intended to comply with the ITU advanced notification procedure.

Since the time of its inception, almost one hundred new or major modifications to existing systems have been examined by this procedure. Some of the systems which have passed through this procedure include:

Table 3.2 - Summary Below 40 GHz (of New Space Service Allocations)

	AMATEUR	COMMUNICATION SATELLITE	DISTRIBUTION SATELLITE (B/C SAT)	EARTH SCIENCES SATELLITE	BROADCASTING SATELLITE	METEOROLOGICAL SATELLITE	RADIO ASTRONOMY	SPACE RESEARCH	AERO SPACE TECHNIQUES	MARITIME SPACE TECHNIQUES	MOBILE SPACE TECHNIQUES	STAND. FREQ. SATELLITE	TOTAL
IMPROVED						100 MHz (100 MHz)	14.25 MHz (13.9 MHz	22 MHz (22 MHz)					135.25 MHz (135.9 MHz)
NEW EXCLUSIVE		3000 MHz (3000 MHz)					400.02 MHz (400.02 MHz)		30 MHz (30 MHz)	5.5 MHz (15.2 MHz)	0.1 MHz (0.1 MHz)	0.1 MHz (0.1 MHz)	3435.72 MHz (3445.42 MHz)
NEW SHARED	1405.6 MHz (57.5 MHz)	6240* MHz (*6320 MHz)	190* MHz (*190 MHz)	1312* MHz (*1292 MHz)	796 MHz (670 MHz)	167* MHz (*167 MHz)	91 MHz (91 MHz)	*2182.85 MHz (*2182.85 MHz)	10 MHz* (*2 MHz)	*10 MHz (*2 MHz)	158.1 MHz (153.1 MHz)		12082.45 MHz (10813.45 MHz)
FAR SIDE OF MOON							24456.45 MHz (**)						24456.45 MHz
ABOVE THE F							12.5 MHz						12.5 MHz (0 MHz)
DELETED						-10 MHz (-10 MHz)	-100.09 MHz (-100.09 MHz)	-15.06 MHz (-5.06 MHz)					-125.15 MHz (-115.15 MHz)

* NOTE FOLLOWING SHARING ARRANGEMENTS WITHIN THE NEW PROVISIONS:

ISS, SPACE RESEARCH AND MET SAT	95 MHz	(95 MHz)
ESS, AND MET SAT	32 MHz	(22 MHz)
AERO AND MARITIME	10 MHz	(2 MHz)
COMM SAT & DISTRIBUTION SAT	190 MHz	(70 MHz)

(** RECOMMENDATION APPROVED FOR PROTECTION ON THE FAR SIDE OF THE MOON)

Table 3.3 - Stages of Systems Review

Stage 1 - Planning (conceptional) Stage

1. Space Systems -All new system and subsystem concepts shall be reviewed as early as significant system definition data can be made available. Such review should be completed not less than one year prior to the initial date of operation.

2. Terrestrial Systems - Systems and subsystems involving new or unconventional concepts and techniques as regards spectrum use, or estimated to have a major impact on spectrum usage as identified by user agencies, OTP, or IRAC, shall be reviewed upon completion of concept definition. Normally, this review will be conducted three years prior to the planned date of initial operation.

Stage 2 - Experimental Stage (new techniques or equipments)

Experimentation involving either space or terrestrial techniques that looks toward the development or feasibility of an operational telecommunication system or subsystems.

Stage 3 - Development Stage

1. Space Systems - All new systems and subsystems shall be reviewed or, in appropriate cases, previous reports shall be updated prior to commencing development actions. Such reviews will normally be initiated a minimum of 18 months prior to commencement of development actions. No frequency assignment action will be effected until reviewing action has been completed.

2. Terrestrial Systems - New systems and subsystems, as defined in Sec. 8.3.3, para. b*, shall be reviewed or; in appropriate cases, previous reviews shall be updated prior to commencing development actions. Such reviews will normally be initiated 6 to 18 months prior to commencement of development actions. No frequency assignment action will be effected until reviewing action has been completed.

Stage 4 - Procurement Stage

1. Space Systems - All new systems and subsystems shall be reviewed or, in appropriate cases, previous reports shall be updated prior to commencing procurement actions. Such reviews will normally be initiated a minimum of 18 months prior to the commencement of procurement actions. No frequency assignment action will be effected until reviewing action has been completed.

2. Terrestrial Systems - New systems and subsystems, as defined in Sec. 8.3.3, para. b*, shall be reviewed or; in appropriate cases, previous reviews shall be updated prior to commencing procurement actions. Such reviews will normally be initiated 6 to 18 months prior to the commencement of procurement actions. No frequency assignment action will be effected until reviewing action has been completed.

* of the OTP

Army Proximity Warning Device, Transit Improvement Program, NATO SATCOM III, MARISAT, SPACE SHUTTLE, Earth Resources Survey Operational Satellite System, Citizens Alarm System, Electronic Cargo Security System, and Viking 1 and 2.

Some of these systems have been approved, *as submitted*; others have had recommendations made for modification. The types of analyses made at the various stages are indicated below:

Stage 1

In the conceptual stage where much of the system data will be estimated, only gross calculations may be achievable for a general evaluation of spectrum impact that will be subject to adjustment during later stages. However, checks will be made against existing standards and sharing criteria, comparison made with known similar systems, and an evaluation of spectrum efficiency performed. Calculations required in connection with the International Advance Publication on Space Systems will also be performed at this stage.

Stage 2

In the experimental stage, the foregoing types of analyses will be applied where appropriate with more specific EMC analysis against a typical environment being added, where experimental testing of technically-defined equipments is involved. Recommendations for changes to equipment characteristics and contemplated operational employment/deployment will be provided, where appropriate.

Stage 3

In the pre-development phase, more detailed EMC analysis will be performed, using measured data from experimentation when available. Appropriate recommendations as to equipment characteristics and/or operational equipment/deployment will be developed.

Stage 4

In the pre-procurement phase, detailed EMC analyses will be updated, as required, to include consideration of frequency assignments for specific system deployment. Appropriate recommendations as to equipment characteristics and/or operational limitations will be provided.

Since its introduction, this technique has proved to be one of the most successful of modern spectrum management methods.

3.3 RADIO BAND ASSESSMENTS

This section will discuss another recently developed spectrum control technique: Radio Band Assessments. This technique is a planning tool for relatively large segments of spectrum. Typically, an assessment will include a number of different allocations, where there are a number of systems in various stages of experimentation, planning and operation.

These assessments are carried out by the Spectrum Management Support Division of the Office of Telecommunications, Department of Commerce, under the direction of OTP.

The purpose of such assessments is to identify intersystem interference problems which may arise and to recommend possible solutions. Normally, the interconnections fall into three categories:

1. Serious Problems - these are interactions where solutions are difficult to achieve;

2. Manageable Problems - these are problems where it appears that feasible and somewhat straightforward solutions exist.

3. No Problem - these are situations in which the interference level is approximately equal to or less than receiver noise even under worst-case conditions of tuning, antenna coupling, and normal separations.

The technique is best illustrated by example. One of the results of the WARC-ST in 1971 was to change the structure of the allocation table between 1535-1660 MHz.[2] The new structure made provisions for maritime and aeronautical satellite services, and for satellite radionavigation. In addition, footnotes permit these bands to be used for satellite radio navigation and communication facilities in the portion of the band allocated in a primary basis to Aeronautical Radio Navigation.

A preliminary analysis indicated that the allocations in the bands between 1535-1660 MHz would be used in the fashion indicated in Fig. 3.2.

3.3.1 System Identification

The assessment begins with the identification of the planned or existing systems. These take the form shown below:

Radar Altimeters: These systems are currently operational in this band. Both pulsed and FM systems are in use on both civil and military aircraft. New military aircraft designs will not use radar altimeters in this band. However, the existing inventory of military altimeter hardware in this band probably will

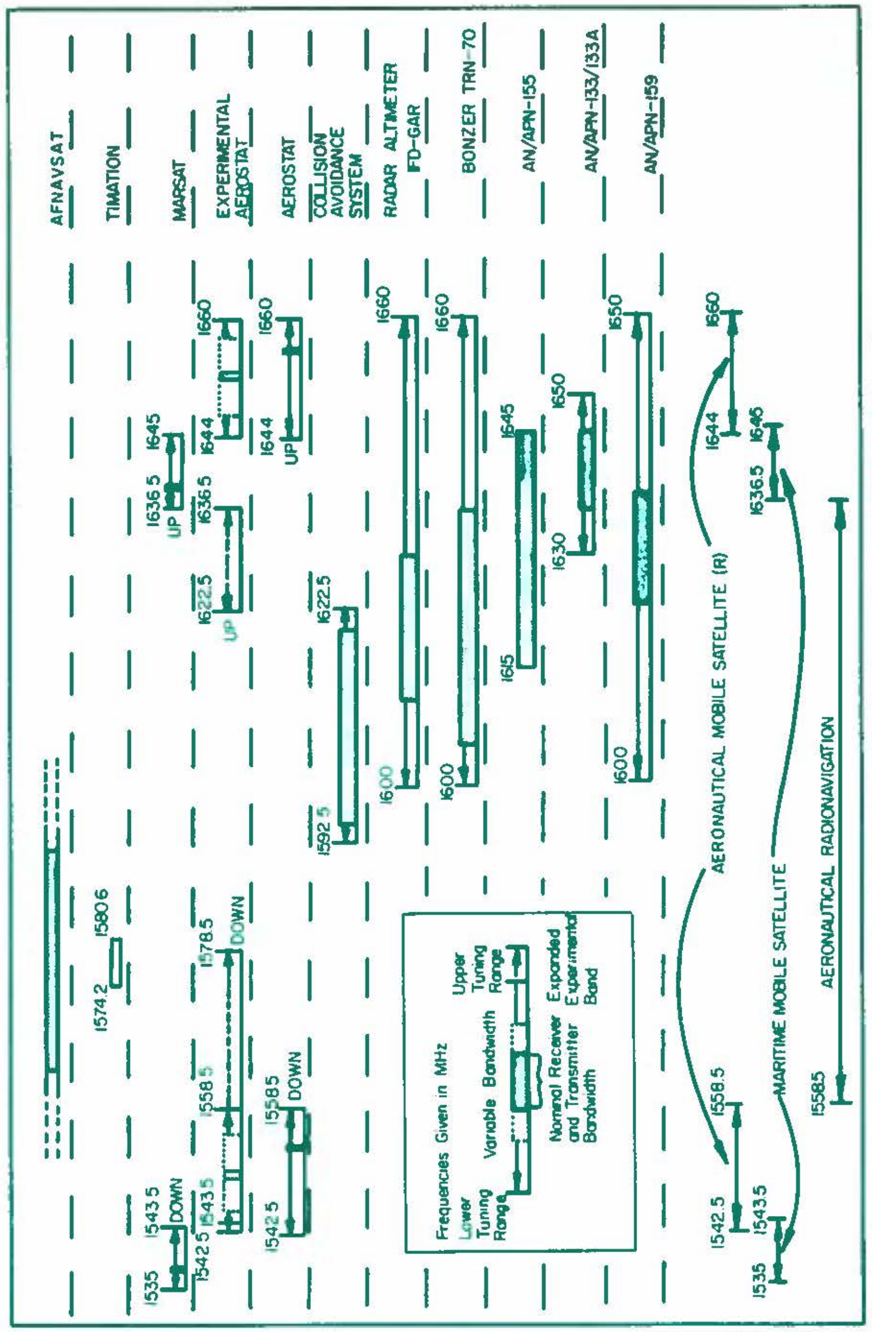


Figure 3.2 - Spectrum Allocations Systems in the 1535-1660 MHz Frequency Domain.

be installed on military aircraft still in production; if those aircraft types were originally outfitted with them. Thus, as the aircraft systems using these particular radar altimeters are phased out of service, the L-band military radar altimeter will be eventually eliminated. The civilian L-band radar altimeters are no longer in production, but a sizeable number are currently estimated to be in use. The rate of removal of the altimeters from L-band is unknown, but is assumed to be no more than a few percent per year for both the civilian and military versions.

Collision Avoidance System: Three major candidate aircraft collision avoidance systems, two using transponder techniques and the third using time/frequency techniques, are now in competition to become designated a national standard system. The three manufacturers; Honeywell, McDonnell-Douglas, and RCA, have built prototype systems which are currently undergoing flight and compatibility tests for an interagency committee. Technical specifications for the three systems are contained in the Appendices.

Satellite Navigation: A DOD Navigation Satellite System (DNSS) has been proposed for this band. One contender for DNSS is the Air Force Navigation Satellite (AFNAVSAT). General systems data are available, but the RF packages are not yet defined. The other system possibility is the L-band Navy Timation. Technical details on this system are also very limited. However, sufficient system parameters of both are known to allow parametric compatibility estimates with the other systems. Only one of these navigation systems will be fully developed for the military and possibly for the civilian community.

Satellite Communication/Surveillance: The FAA and MARAD have proposed satellite systems for communication and/or surveillance. The Maritime Administration (MARAD) has had several proposals for systems. Recently, COMSAT Corporation won approval to proceed with an interim system in this band and contracted with Hughes for the equipment.

As is apparent, there is considerable opportunity for problems.

3.3.2 Analysis

The next step involves identifying the interactions between the systems in the band concerned. A pictorial representation of these interactions is given in Fig. 3.3. There are at least eight major systems in existence or planned in this band. These systems give rise to 49 different possible interactions.

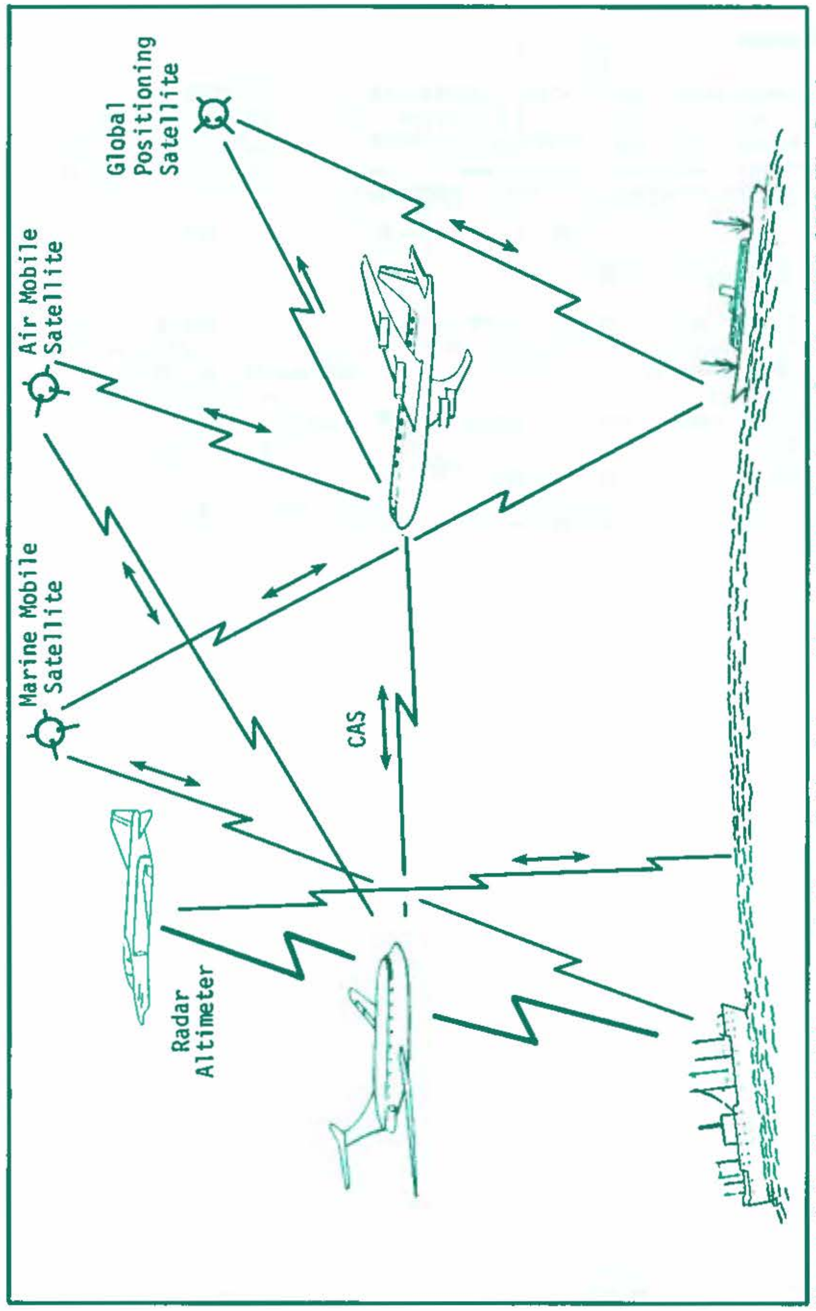


Figure 3.3- Pictorial Representation of the Interaction Between Systems in the 1535-1660 MHz Bands

be installed on military aircraft still in production; if those aircraft types were originally outfitted with them. Thus, as the aircraft systems using these particular radar altimeters are phased out of service, the L-band military radar altimeter will be eventually eliminated. The civilian L-band radar altimeters are no longer in production, but a sizeable number are currently estimated to be in use. The rate of removal of the altimeters from L-band is unknown, but is assumed to be no more than a few percent per year for both the civilian and military versions.

Collision Avoidance System: Three major candidate aircraft collision avoidance systems, two using transponder techniques and the third using time/frequency techniques, are now in competition to become designated a national standard system. The three manufacturers; Honeywell, McDonnell-Douglas, and RCA, have built prototype systems which are currently undergoing flight and compatibility tests for an interagency committee. Technical specifications for the three systems are contained in the Appendices.

Satellite Navigation: A DOD Navigation Satellite System (DNSS) has been proposed for this band. One contender for DNSS is the Air Force Navigation Satellite (AFNAVSAT). General systems data are available, but the RF packages are not yet defined. The other system possibility is the L-band Navy Timation. Technical details on this system are also very limited. However, sufficient system parameters of both are known to allow parametric compatibility estimates with the other systems. Only one of these navigation systems will be fully developed for the military and possibly for the civilian community.

Satellite Communication/Surveillance: The FAA and MARAD have proposed satellite systems for communication and/or surveillance. The Maritime Administration (MARAD) has had several proposals for systems. Recently, COMSAT Corporation won approval to proceed with an interim system in this band and contracted with Hughes for the equipment.

As is apparent, there is considerable opportunity for problems.

3.3.2 Analysis

The next step involves identifying the interactions between the systems in the band concerned. A pictorial representation of these interactions is given in Fig. 3.3. There are at least eight major systems in existence or planned in this band. These systems give rise to 49 different possible interactions.

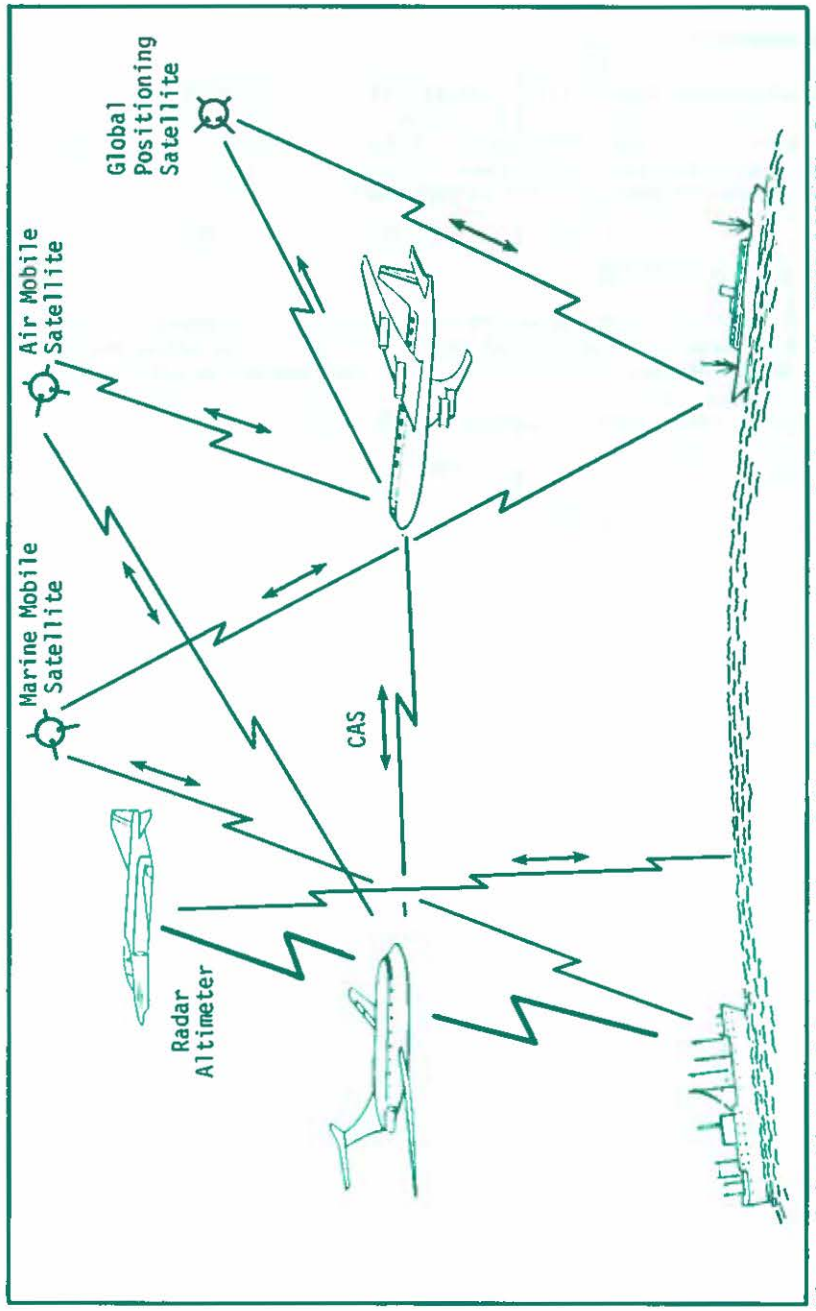


Figure 3.3- Pictorial Representation of the Interaction Between Systems in the 1535-1660 MHz Bands

3.3.3 Assessment

The assessment begins with identifying which of the 49 interactions fall into the category of a serious problem, manageable problem, or no problem. For this illustration, these are categorized in Fig. 3.4. There are two serious problems, 18 manageable problems, and 29 where there are considered to be no problems.

3.3.3.1 Serious Problem

All the serious problems arise from the radar Altimeters. The analysis indicates that they could seriously impair the operation of the Collision Avoidance Systems (CAS) by a combination of pulse repetition rate and spectrum splatter. This is due to the fact that altimeters require wide emission bandwidths in order to perform their altitude determination function. As a result, these emissions involve the pass-bands of the CAS systems. The problem is serious because several millions of dollars worth of altimeters already in use would have to be modified in order to accommodate the CAS.

3.3.3.2 Manageable Problems

The manageable problems fall into three categories:

1) Spurious emission control;

2) frequency assignment control;

3) system design changes.

1. Spurious Emission Control - Under present rules for spurious emission suppression, the MARSAT and MAROTS could cause interference to the CAS, AEROSAT and MAROTS could cause interference to the CAS, AEROSAT, and DNSS; and theAEROSAT could cause interference to the CAS and the DNSS.

2. Frequency Assignment Control - There is overlap in frequency assignments between the altimeters and the MARSAT and AEROSAT.

3. System Design Change - The MARISAT and MAROTS would be incompatible if the two systems were to remain approximately co-located on the geostationary orbit.

3.3.3.3 No Problem

All the other interaction pairs appear to be compatible; i.e., the predicted interference was below the interference with receiver

Sec. 3.3 Radio Band Assessments

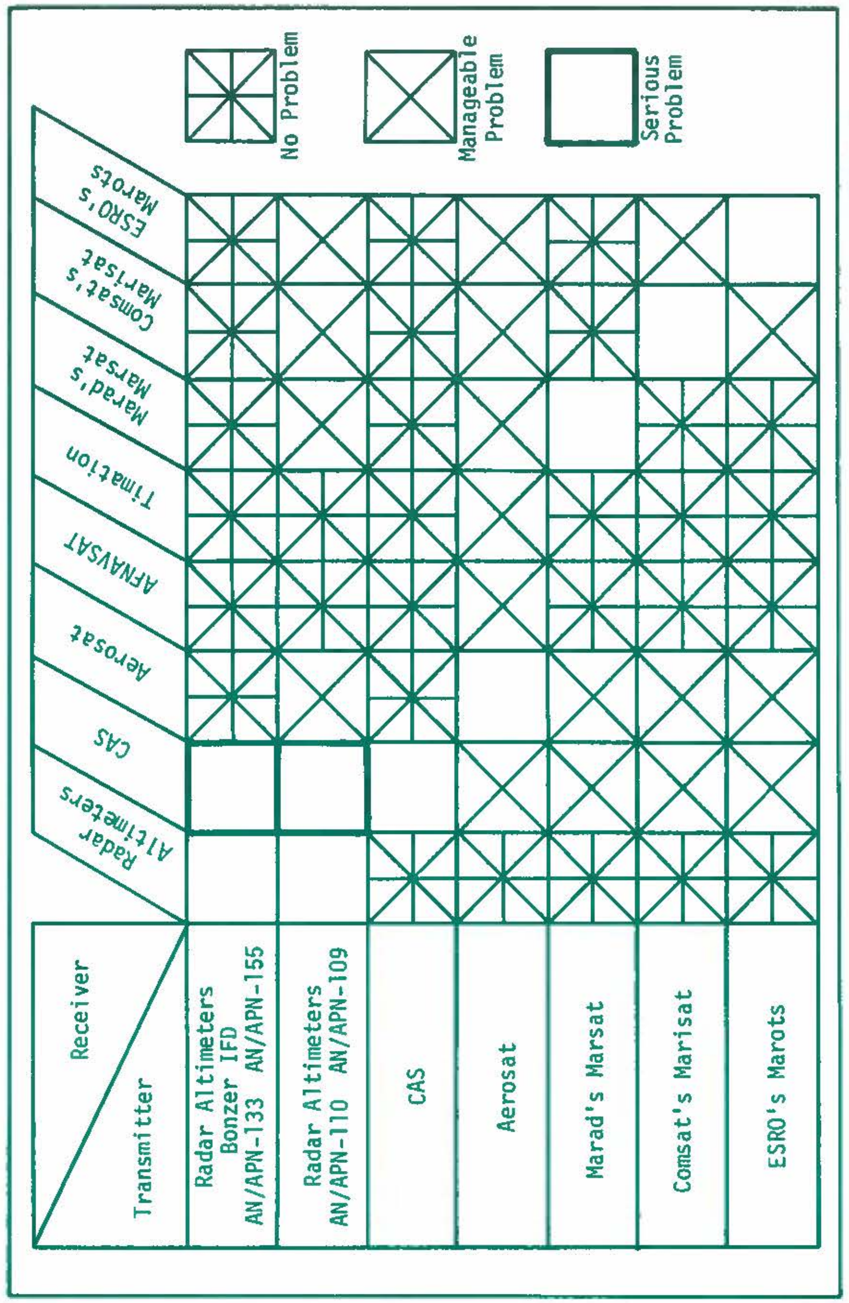


Figure 3.4 - Summary of 1535-1660 MHz Band Interactions

noise floor for natural separation distances.

3.3.4 Solutions

The application of the band assessment techniques has identified 20 serious and manageable problems for this band. The analysis is completed with recommended approaches to the solutions.

3.3.4.1 Difficult Problems

The altimeter can be made more compatibile with the CAS system by giving careful consideration to tuning the frequency of the altimeter to the high end of the band. In addition, the altimeter transmitted emission could be filtered to increase the transmitted pulse rise and fall times.

3.3.4.2 Manageable Problems

The spurious emissions of offending transmitters can achieve design controls which would lower the interference power to acceptable levels. The frequency control problems involving the altimeters are manageable because the interfering signal is only momentary. The MAROTS AND MARISAT can be made compatible by either repositioning the satellites or by polarization discrimination.

Band assessments are resulting in improved spectrum utilization through the avoidance of costly system design errors. The assessment described in the example, and several already completed or under way, have resulted in bringing about such changes. Band assessments are also under way in the bands 2700-2900, 7125-8400, and 960-1315 MHz.

3.4 ADVANCED NOTIFICATION METHODS

The 1971 World Administrative Radio Conference on Space Telecommunications made available over 15,000 MHz of new spectrum for various types of space services. This spectrum was made available to accommodate the anticipated growth in satellite systems. The type of satellite envisioned for use in many applications was that which could be placed into geostationary orbit. A satellite when placed in this orbit is located at some specific longitude and at about 22,300 miles altitude. It rotates about the earth at the same rate the earth rotates on its axis. There is a very definite upper limit to the number of satellites which can be accommodated in any particular band in this orbit.

With this in mind, the WARC-ST adopted several international spectrum management methods which were intended to provide a basis for ensuring that geostationary satellites and satellite earth stations operating in the same band would not cause interference to each other, or to existing terrestrial systems. These methods were necessitated by the fact that radio signals, particularly those being radiated from an altitude of 22,300 miles, do not respect international boundries.

3.4.1 Satellite System Coordination

The first of these methods concerns satellite system coordination. Article 9A of the International Radio Regulations,[3] paragraphs 639AJ and 639AK state:

> 639AJ §2. (1) Before an administration notifies to the use of any frequency assignment to a space station on a geostationary satellite or to an earth station that is to communicate with a space station on a geostationary satellite, it shall effect co-ordination of the assignment with any other administration whose assignment in the same band for a space station on a geostationary satellite or for an earth station that communicates with a space station on a geostationary satellite is recorded in the Master Register, or has been co-ordinated or is being co-ordinated under the provisions of this paragraph. For this purpose, the administration requesting co-ordination shall send to any other such administration the information listed in Appendix 1A.
>
> 639AK (2) No co-ordination under No. 639AJ is required:
>
> a) when the use of a new frequency assignment will cause, to any service of another admin istration, an increase in the noise temperature of any space station receiver or earth station receiver, or an increase in the equivalent satellite link noise

> temperature, as appropriate, not exceeding the pre-determined increase of noise temperature calculated in accordance with the method given in Appendix 29.

However, if the increase in noise temperature from one Administration's satellite system in another Administration's satellite system is greater than 2%, then further discussions are required among the Administration concerned to determine if there is a real interference problem.

This is called the *Advanced Notification Procedure* and may be initiated anytime up to five years before a satellite system is to be launched.

This procedure is predicated on the fact that the increase in noise temperature in one system due to another can be calculated quite easily with a limited amount of information about the other system. Specifically, the increase in equivalent noise temperature for the entire satellite link in network R at the receiver input of the receiving earth station e_R due to interference from network R', may be given by:

$$\Delta T = \gamma \Delta T_s + \Delta T_e \tag{1}$$

$$\Delta T_s = \frac{P_e g_1'(\theta) g_2(\delta)_{e'}}{k l_u} \tag{2}$$

$$\Delta T_e = \frac{P_s' g_3' \eta_e g_4 \theta}{k l_u} \tag{3}$$

The definition of the symbols used in equations (1), (2), and (3) are given in Table 3.4. The interference geometry between the two satellite networks, R and R', is indicated in Fig. 3.5.

The information necessary to perform the calculations of Eq. (1), (2), and (3) is included in Appendix 1B of the Radio Regulations and incorporated as Appendix 29 of the Radio Regulations. This method is based on the concept that the noise temperature of the system receiving interference undergoes an apparent increase due to the effect of interference. It can therefore be used irrespective of the modulation characteristics of the satellite networks concerned, and the precise frequencies employed.

3.4.2 Earth Station Coordination

The other advance notification method concerns the placement of satellite earth stations. This is a procedure required by Article 9A of the Rules and Regulations to insure that interference is neither caused to, nor received from, terrestrial stations operating in the same frequency band. The requirement for this type of coordination

Table 3.4 - Factors in ΔT Calculation

ΔT_s	:	increase in the receiver noise temperature of the satellite S caused by interference in the receiver of this satellite (K);
ΔT_e	:	increase in the receiver noise temperature of the earth e_R caused by interference in the receiver of this station (K);
p_s	:	maximum power density per Hz delivered to the antenna of satellite S (averaged over the worst 4 kHz band for a carrier frequency below 15 GHz or over the worst 1 MHz band above 15 GHz)(W/Hz);
$g_3(\eta)$	:	transmitting antenna gain of satellite S in the direction η (numerical power ratio);
	η_A :	direction, from Satellite S, of the receiving earth station e_R of satellite link A;
	η_e':	direction, from satellite S, of the receiving earth station e_R' of satellite link A';
		Note. - The product $p_s g_3(\eta_e')$ is the maximum e.i.r.p. per Hz of satellite S in the direction of the receiving earth station e_R' of satellite link A';
	η_s':	direction, from satellite S, of satellite S';
p_e	:	maximum power density per Hz delivered to the antenna of the transmitting earth station e_T (averaged over the worst 4 kHz band for a carrier frequency below 15 GHz or over the worst 1 MHz band above 15 GHz)(W/Hz);
$g_2(\delta)$	:	receiving antenna gain of satellite S in the direction δ (numerical power ratio);
	δ_A :	direction, from satellite S, of the transmitting earth station e_T of satellite link A;
	δ_e':	direction, from satellite S, of the transmitting earth station e_T' of satellite link A';
	δ_s':	direction, from satellite S, of satellite S';
g_1	:	transmitting antenna gain of the transmitting earth station e_T inthe direction of satellite S (numerical power ratio);
$g_1(\theta)$	:	transmitting antenna gain of the earth station e_T in the direction of satellite S' (numerical power ratio);
g_4	:	receiving antenna gain of the earth station e_R in the direction of satellite S (numerical power ratio);

Table 3.4 - (Continued)

$g_4(\theta)$	:	receiving antenna gain of the earth station e_R in the direction of satellite S´ (numerical power ratio);
k	:	Boltzmann's constant (J/K);
l	:	free-space transmission loss on the down-path (numerical power ratio)*;
l_u	:	free-space transmission loss on the up-path (numerical power ratio)*;
γ	:	transmission gain of the satellite link evaluated from the output of the receiving antenna of the space station S to the output of the receiving antenna of the earth station e_R (numerical power ratio, usually less than 1), given by: $\gamma = \dfrac{p_s g_3(\eta_A) g_4 l_u}{p_e g_1 g_2(\delta_A) l_u}$
θ	:	geocentric angular separation between two satellites (degrees)*.

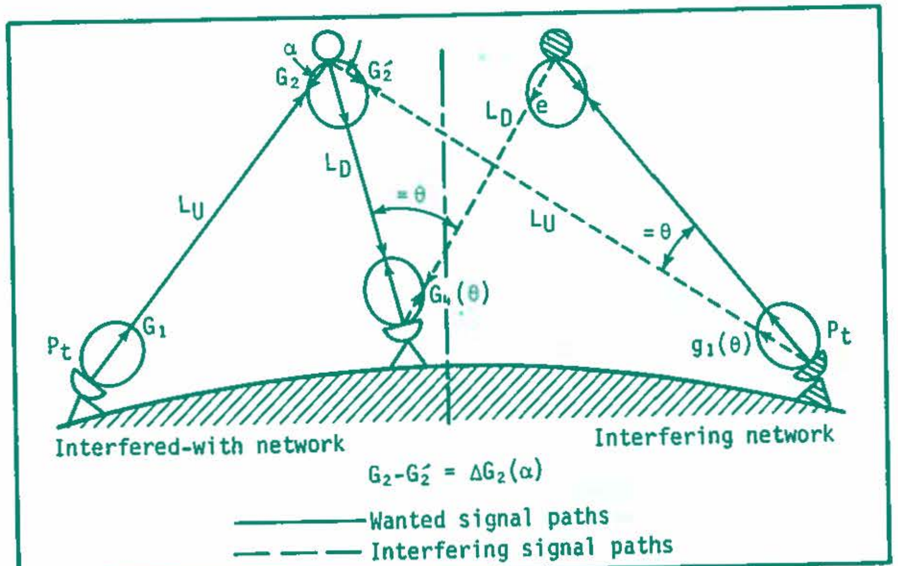


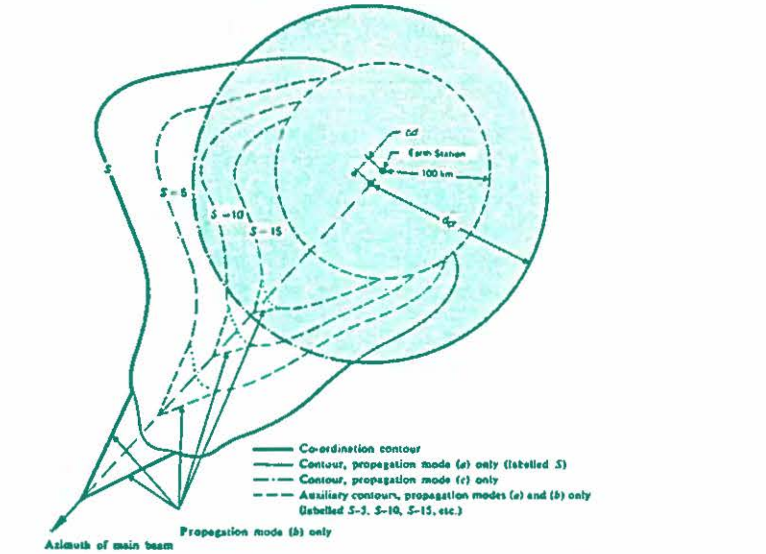
Figure 3.5 - Interference Geometry Between Two Satellite Networks

derives from the fact that in certain bands satellite systems share the band with already existing terrestrial stations. In this case, calculations are performed in accordance with Appendix 28 of the ITU Radio Regulations to determine permissible values of interference to be exceeded no more than p per cent of the time at the receiver input of a station suffering interference. This is obtained from the following equations:

$$P_r(p) = 10 \log_{10}(kT_rB) + J + M(p) - W \qquad (4)$$

$$M(p) = M(P_o/n) = M_o(p_o) \qquad (5)$$

Table 3.5 explains the symbols. Interference levels are associated with specific distances from the earth station location for every degree of azimuth. If a terrestrial station lies within this distance then more detailed coordination may be required. On the other hand, if there are no terrestrial stations within the contour, an administration must simply file with the ITU in the particular region concerned. Appendix 28 provides the methodology for making this calculation for a variety of frequencies, modulation schemes, and propagation conditions. An example of an earth station distance coordination contour is shown in Fig. 3.6.



If by using the auxiliary contours it is seen that a terrestrial station can be eliminated with respect to the great circle propagation mechanism then:

i) if that terrestrial station is outside of the shaded area (rain-scatter mode), it may be eliminated from any further consideration;

ii) if that terrestrial station is within the shaded area (rain-scatter mode), it must still be considered, but simply for the rain-scatter propagation mode only.

Figure 3.6 - Coordination Distance Contour of Transmitting Earth Station

Table 3.5 - Symbols

k = Boltzmann's constant (1.38×10^{-23} joule per K);
T_r = thermal noise temperature of the receiving system (K);
B = reference bandwidth (in Hz)(bandwidth, of concern to the interfered with system, over which the interference power can be averaged);
J = ratio (in dB) of the permissible long term (20% of the time interfering power to the thermal noise power in the receiving system([1]);

- p_o = percentage of the time during which the interference from all sources may exceed the permissible value;
- n = number of expected entries of interference, assumed to be uncorrelated;
- p = percentage of the time during which the interference from one source may exceed the permissible value; since the entries are not likely to occur simultaneously $p=p_o/n$;
- $M_o(p_o)$ = ratio (in dB) between the permissible interference powers during p_o% and 20% of the time respectively, for all entries of interference([2]);
- M(p) = ratio (in dB) between the permissible interference powers during p% of the time for one entry of interference, and during 20% of the time for all entries of interference, respectively;

Notes:

([1]) The factor J (in dB) is defined as the ratio of total permissible long-term (20% of the time) interference power in the system, to the long-term thermal noise power in a single receiver. For example, in a 50-hop terrestrial line-of-sight radio relay hypothetical reference circuit, the total allowable additive interference power is 1,000 pW0p (C.C.I.R. Recommendation 357-1) and the mean thermal noise power in a single hop may be assumed to be 25 pW0p. Therefore, in a FDM/FM system, the ratio of the interference noise power to the thermal noise power in a 4 kHz band is the same before and after demodulation, J = 16 dB. In a satellite link in the fixed-satellite service, the total allowable interference power is also 1,000 pW0p (C.C.I.R. Recommendation 356-2), but the thermal noise contribution of the down path is not likely to exceed 7,000 pW0p, hence $J \geqslant -8{\cdot}5$ dB. In digital systems it may be necessary to protect each communication path individually, and in that case, long term interference power may be of the same order of magnitude as long-term thermal noise, hence J = 0 dB. as long-term thermal noise, hence J = 0 dB.

([2]) $M_o(p_o)$ (in dB) is the "interference margin" between the long-term (20%) and the short-term (p_o%) allowable interference powers. For analogue radio-relay and fixed-satellite systems in bands between 1 and 15 GHz, this is the ratio (in dB) between 50000 and 1000 pW0p (17 dB). In the case of digital systems, $M_o(p_o)$ may tentatively be set equal to the fading margin which depends, inter alia, on the local rain climate.

3.5 FCC NOTICES

Although not commonly recognized as such, the procedural mechanisms of the Federal Communications Commission can constitute planning techniques. This is particularly true of Notices of Inquiry (NOI). Such notices may be initiated by the FCC on its own, or in response to a petition from a party in the private sector.

Typically, such an inquiry is initiated to obtain information on a particular area of interest. The information gained from an initial inquiry may lead to further inquiries on the same, or related subjects.

This approach is necessitated by the Administrative procedures Act. This act requires regulatory commissions, such as the FCC, to follow certain well-established and documented procedures with regard to carrying out their functions in the areas of their jurisdiction. In the case of the FCC, jurisdiction concerns the entire private sector, and state and local government use of communications. These regulatory provisions are intended to insure that all parties which may be effected by the rules and regulations adopted by the FCC have an opportunity to comment.

Notices of inquiry fall into several categories, characterized by how they are concluded:

3.5.1 Pure Inquiry

Such an NOI does nothing more than obtain information on a particular subject. It may involve a new technology or a new service, or a modification of an existing concept. The commission initiates an inquiry because it may continue the inquiry for some period of time, and may eventually drop it. Such may be the case, for example, with regard to an inquiry to determine the impact of putting ignition noise suppressors on all automobiles.

3.5.2 International Conference Inquiry

This form of NOI is most explicitly involved in planning. Such an inquiry is used to ascertain anticipated spectrum requirements in preparation for an international conference. Successive inquiries may be issued, reflecting new assessments by the FCC with regard to what the U.S. proposals should look like for such a conference. Subsequent to the holding of the conferences, the inquiry will terminate with a Notice of Proposed Rule Making (NPRM), which suggests the FCC Rules and Regulations to implement the results of the conference. Finally, after receiving comments on the NPRM, the FCC will issue a Report and Order, which also usually terminates the proceeding.

In preparing for the 1971 WARC-ST, the Commission issued approximately six NOI's beginning three years before the conference. As of late 1976, several NOI's had been issued in preparation for the 1979 World Administrative Conference.

3.5.3 Policy Formulation Inquiry

Such an inquiry is focused on breaking new ground. It normally culminates in a Report and Order which establishes a precedent in a particular area of communications regulation. Such was the case of the Sixth Report and Order in the Inquiry involving the structure under which television stations would be implemented. This order has stood for over twenty years. In 1967, the American Broadcasting Company petitioned the FCC for permission to operate a domestic satellite for distributing television programs to its affiliate TV stations. This petition precipitated an inquiry that covered approximately eight years, culminating in a Report and Order which instituted an *Open Skies* policy with regard to the implementation of U.S. domestic satellites.

These procedural inquiries are the principal spectrum planning mechanism of the FCC. While they are tedious and time-consuming, they are distinct facets of United States democractic institutions.

3.6 REFERENCES

1. Manual of Regulations and Procedures for Radio Frequency Management; Office of Telecommunications Policy; 1975.

2. Compatibility of Radio Systems in the Band 1535-1600 MHz; OT, Department of Commerce; 1975.

3. International Radio Regulations, International Telecommunications Union (ITU); Geneva, Switzerland.

4. Technology for Improved Use of the Spectrum; Aerospace Corporation Contract Report for OTP; 1976.

CHAPTER 4

SPECTRUM STANDARDS

The technical objective of spectrum management is to establish criteria which will permit communication electronic systems to perform their intended information transfer functions in a satisfactory manner, using the minimum practicable amount of spectrum. This chapter will describe these criteria for basic functional Radio Services.

4.1 SPECTRUM UTILIZATION

CCIR Recommendations that effect spectrum utilization have been generally adopted by the OTP and FCC. Some of these are listed below:

Rec. 3283	Spectrum and bandwidths of emission
Rec. 329-2	Spurious radiation
Rec. 337	Channel separation
Rec. 433-2	Methods for the measurement of radio interference as determination of tolerable levels of interference
Report 181	Frequency tolerance of transmitters

An example is given in Table 4.1, which shows the necessary bandwidths and tolerances for transmitters in different parts of the spectrum for different services. These serve as guides and have been adopted by many countries as a basis for their domestic spectrum standards.

Table 4.1 - Bandwidths and Tolerances for Various Services

Frequency bands and categories of stations	Representative value of necessary bandwidth of emission (kHz)	Tolerance achievable now or in the near future (Hz)	Ultimate tolerance (Hz)
(1)	(2)	(3)	(4)
Band 535-1605 kHz			
Breadcasting stations	10	10	10
Band 1605-4000 kHz			
1. Fixed stations:			
A3	6	60	60
A3H-A3J	3	10	10
A3A-A3B	3-6	10	10
2. Land stations:			
A3	6	20	10
A3H-A3A-A3J	3	20	10
3. Mobile stations:			
(a) Ship stations: A3H-A3A-A3J	3	100	20
(b) Land mobile stations: A3H-A3J	3	100	20
(c) Aircraft stations: A3H-A3J	3	20	20
4. Broadcasting stations	10	10	10
Band 4-29.7 MHz			
1. Fixed stations:			
(a) Telephone network with several stations on a single frequency: A3A-A3J	3	10	10
(b) Other fixed stations	1.7 to 12	10	3
2. Land stations:			
(a) Coast stations:			
A3H-A3A-A3J	3	10	10
A7A	3	3	3(1)
A1	0·1	100	100
Other than A1	1·7	17	17
(b) Aeronautical stations: A3H-A3J	3	10	10
(c) Base stations: A3H-A3J	3	20	10
3. Mobile stations:			
(a) Ship stations: A3H-A3A-A3J	3	50	20
F1	0·2	10	10(1)
(b) Aircraft stations: A3H-A3J	3	20	20
(c) Land mobile stations: A3H-A3J	3	50	20
4. Broadcasting stations	10	10	10
Band 29.7-108 MHz		(kHz)	(kHz)
1. Land stations (50 MHz)	16	1	
2. Mobile stations (50 MHz)	16	1	
3. Broadcasting FM stations	200	2	2
4. Television stations	6000	2·5 Hz(2)	2·5 Hz(2)
Band 108-470 MHz		(kHz)	(kHz)
1. Land stations:			
(a) Coast stations (156 MHz)	16	1	0·36
(b) Base stations (470 MHz)	16	1·5	
2. Mobile stations:			
(a) Ship stations (156 MHz)	16	1·6	
(b) Land mobile stations (470 MHz)	16	2·5	
3. Television stations	6000	2·5 Hz(2)	2·5 Hz(2)

(1) This tolerance is required for reception without automatic frequency control, for narrow-band frequency-modulation telegraph channels.
(2) The tolerance of the sound-channel carrier with respect to the visual carrier frequency is [illegible] kHz.

4.2 POINT-TO-POINT COMMUNICATION SERVICES

The principal spectrum management standards with regard to domestic spectrum use may be found in the OTP Manual, Chap. 5, and in various parts of the FCC Rules and Regulations. From a spectrum standpoint, the standards that are of importance concern those characteristics of the transmitter, receiver, and antenna which influence the use of the spectrum. These are *spectrum standards*. These should be differentiated from performance standards and equipment standards. Some of these may be the same as spectrum standards.

As previous chapters have indicated, technology is available to improve standards from a spectrum standpoint. However, the economics of accomplishing this is equally important. Unfortunately, the "spectrum standards" of today have been primarily the consequence of what is technically possible at a reasonable cost. In other words, effective use of the spectrum has not necessarily been a primary consideration.

Typical spectrum standards for microwave point-to-point services may be categorized by the part of the system to which they apply.

The standards described herein are primarily for non-government point-to-point microwave communication systems. At the present, the OTP Manual does not contain any comprehensive microwave spectrum standards.

4.2.1 Transmitters

1) For the point-to-point microwave bands indicated in Table 4.2, the rated output power cannot exceed 20 watts below 10,000 MHz and 10 watts above.

Table 4.2 - Authorized Bandwidths for Microwave Bands

Band (MHz)	Max. Auth. B.W. (MHz)
2110-2130	3.5
2160-2180	3.5
3700-4200	20.0
5925-6425	30.00
10,700-11,700	40.00
13,200-13,250	25.00
17,700-19,700	220.00
21,200-22,000	100.00
22,000-23,600	100.00
27,500-29,500	220.00
31,000-31,200	50.00
38,600-40,000	50.00

2) The maximum authorized bandwidth should not exceed that specified in Table 4.2 for the bands indicated.

3) The frequency tolerance for heterodyne microwave radio systems may be up to 0.01 percent.

4) Spurious emission - the mean power of emissions is required to be attenuated below the mean output power of the transmitter in accordance with the following:

a) For modulation other than digital:

(1) 25 dB below for any frequency removed from the assigned frequency by 50 percent up to and including 100 percent of the authorized bandwidth.

(2) 35 dB below for any frequency removed from the assigned frequency from 100 percent up to and including 250 percent of the authorized bandwidth.

(3) At least 43 + 10 $\log_{10}$ dB or 80 dB, whichever is less, for any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth.

b) For digital modulation techniques:

For any operating frequencies below 15 GHz, the center frequency of which is removed from the assigned frequency by 50 percent or more of the authorized bandwidth, the attenuation is specified as:

$$A = 35 + 0.8(P-50) + 10 \log_{10} B$$

P = percent removed from current frequency
B = authorized bandwidth

Attenuation A is not to exceed 80 dB. For frequencies above 15 GHz, the formulation is the same except that it applies to any 1 MHz band rather than to 4 kHz.

4.2.2 Antennas

1) Directional antennas are required and are specified to be pointing toward the intended receiving stations.

2) New periscope antennas are not normally authorized.

3) The antenna sidelobe suppression is required to meet the

standards as a function of angle, specified in Table 4.3.

Table 4.3 - Microwave Antenna Sidelobe Standard

Angle	Below 5,000 MHz	Above 5,000 MHz
5°≥10°	23 dB	25
10°≥15°	29	29
15°≥20°	33	33
20°≥30°	36	36
30°≥100°	42	42
100°≥180°	55	55

4.2.3 System

1) Frequency diversity operation is not authorized unless it can be demonstrated that there is no alternative.

2) A new applicant for a microwave point-to-point facility must demonstrate coordination with already existing similar operations. In this connection the FCC Rules state:

"All applicants, permittees and licenses shall cooperate fully and make reasonable efforts to resolve technical problems and conflicts that may inhibit the most effective and efficient use of the radio spectrum; however, the party being coordinated with is not obligated to su suggest changes or re-engineer a proposal involving conflicts".[1]

3) The information indicated in Table 4.4 must be filed for every new microwave station.

Table 4.4 - Filing Information For Microwave Station

Transmitting station name
Transmitting station coordinates
Frequencies and polarizations to be added or changed
Transmitting equipment type, its stability, actual output power, and emission designator
Transmitting antenna height above ground level and ground elevations above mean sea level
Receiving station name
Receiving station coordinates
Receiving antenna type model and, if required, a typical pattern and gain
Receiving antenna height above ground level at ground elevation above mean sea level
Path azimuth and distance

4.2.4 Receivers

There are no spectrum standards on receivers. This is a major deficiency.

4.3 RADIODETERMINATION SERVICES

Radiodetermination consists of a composit of Radiolocation and Radionavigation. This section will be primarily concerned with radiolocation, otherwise known as radar. The Federal Government is the principal user of radars in the United States; primarily for air safety and national defense. The principal spectrum standard applicable to all radars is the OTP *Radar Design Objectives and Engineering Criteria*. The rationale for these criteria is to provide a basis for more effective use of the spectrum by radars. Every federal government must meet its specifications prior to obtaining an assignment. The parameters of concern include: emission bandwidth, radiated power, antenna pattern, frequency stability, tunability, spurious radiation, and receiver acceptance bandwidth.

4.3.1 Emission Bandwidth

Radar emission bandwidth is that bandwidth which includes the fundamental frequency and all modulation side bands down to a spectral density of -80 dBm/kHz/meter^2 in the main antenna beam at a distance of 1.85 km (1 nautical mile). This bandwidth for different types of modulation is specified in Table 4.5.[1]

Table 4.5 - Federal Government Radar Emissions Bandwidth Criteria

Modulation	Radar Emission B.W. (MHz)
Pulse	$\frac{2kK}{t} \leq \frac{64}{t}$
Modified Pulse (matched filter, pulse compression, pulse stretch)	$\frac{2kK}{t} + M \leq \frac{64}{t} + M$
CW	$0.0003\ F_o$
FM/CW	$0.0003\ F_o$

Symbols Used

B = emission bandwidth, in MHz

B_c = compression bandwidth, in MHz

B_s = bandwidth of the frequency shift (*modified* radar system) in MHz.

Symbols Used (Cont'd)

B_d = bandwidth of the frequency deviation (peak difference between instantaneous frequency of the modulated wave and the carrier frequency)---(FM/CW radar systems), in MHz.

F_o = nominal operating frequency, in MHz.

M = bandwidth due to modification of pulse or to deviation from carrier frequency, in MHz.

t = pulse duration in μsec. (time between 50% amplitude points of pulse).

t_r = pulse rise time in μsec. (time required for instantaneous amplitude to rise from 10% to 90% of the peak value).

Δf_1 = value of one half the emission bandwidth (B/2).

Δf_2 = ten times value of Δf_1 ($10\Delta f_1$).

P_t = maximum power spectral level of the radar in dBm/kHz.

S = suppression below P_t in dB.

K = t/t_r (ratio of pulse duration to pulse rise time).

k = weighting factor for K. (see Fig. 4.2).

$P_t = P_p + 20 \log_{10} D_c + 10 \log_{10}(1000\ \text{Hz/PR})$ (Conventional pulse)

$P_t = P_p + 20 \log_{10} D_c + 10 \log_{10}(1000\ \text{Hz/PRR}) - 10 \log_{10} d$ (Compressed pulse)

where: P_p = peak power in dBm

D_c = duty cycle

d = pulse compression ratio

PRR = pulse repetition rate in pulses per second.

The radar emission bands outside these bandwidths at the antenna input are not to be greater than the values indicated in Fig. 4.1. At plus or minus the frequency Δf_1 from F_o, the level is to be at least 40 dB below the maximum value. At and beyond Δf_2 from F_o, the level is to be at least the maximum given by:

$$S = P_t - 20 \log_{10} F_o + 100 \geq 40\ \text{dB}$$

4.3.2 Antenna Pattern

The allowable antenna patterns for radars are:

a) Rotation through 360° median gain of -10 dB or less measured in the principal radiation plane.

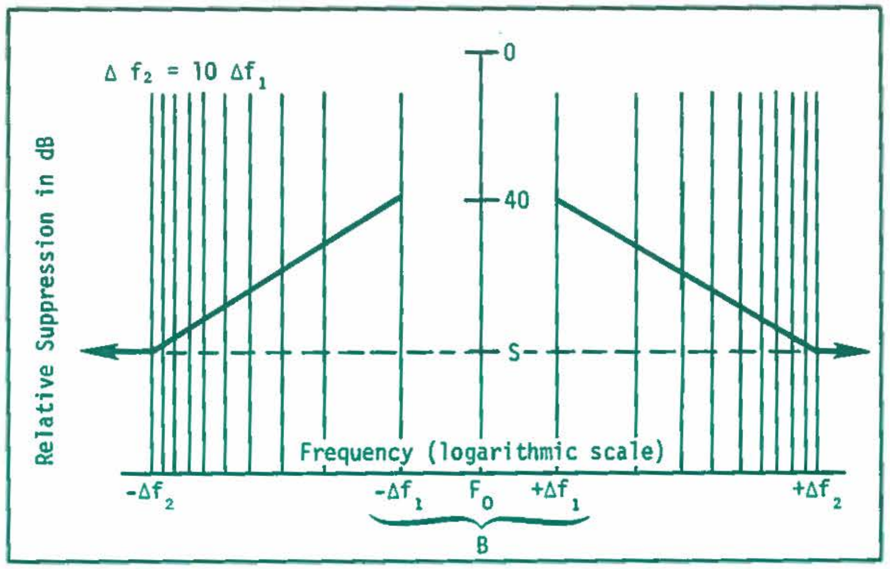


Figure 4.1-Radar Emission Bandwidth and Emission Levels

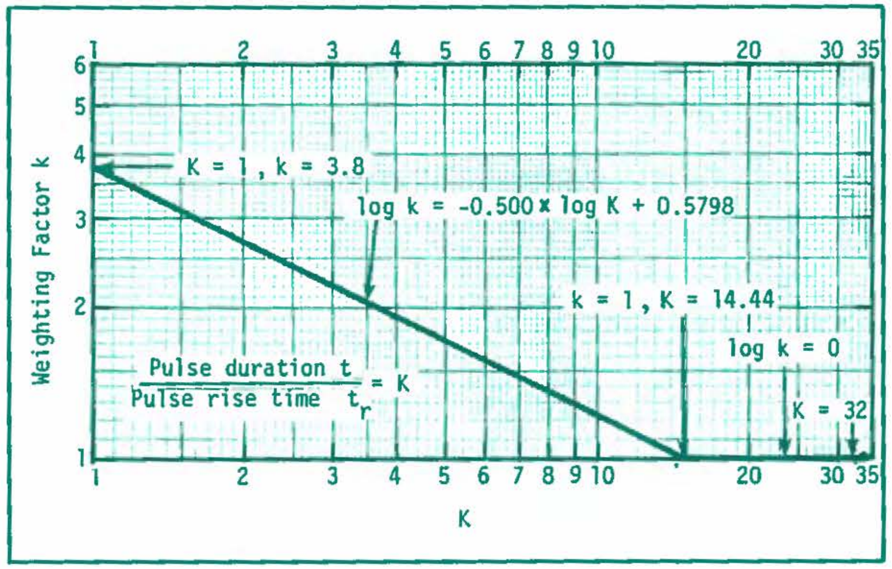


Figure 4.2-Dependence of Weighting Factor k upon K

b) For other antennas, suppression of lobes other than the main antenna, are to meet the following levels referred to the main beam:

(1) major lobes: - 20 dB
(2) all other lobes: - 30 dB

4.3.3 Frequency Stability

This criterion requires that all radar transmitters have a frequency stability consitent with the frequency range indicated below:

Frequency Range (MHz)	Tolerance (parts/million)
960	400
960-4000	800
4000-10,000	1250
10,000-30,000	2500
30,000-40,000	5000

4.3.4 Tunability

Radars can have more flexibility and thereby promote greater electromagnetic compatibility if they have a tuning capability. Therefore, a radar is required to be tunable either over its designated band allocation or over a band which is 10 percent of the nominal frequency.

4.3.5 Receivers

The selectivity of radar receivers is required to be generally commensurate with the transmitter bandwidth indicated in Fig. 4.1. Receivers also must have the capability of switching bandwidth limits whenever there is a change in transmitter bandwidth. Receiver sensitivity is specified as being at least 50 dB; rejection of other spurious responses are to be at least 60 dB; radar local oscillator radiation is not to be greater than -40 dBm at the receiver input terminals.

4.3.6 Measure of Radar Center Frequency

The center frequency of the radar should be measurable to an accuracy of $\pm$ 1 part in 10^6, although $\pm$ 1 part in 10^4 is acceptable. This is to insure adequate field coordination.

4.3.7 Applicability

Effective January 1, 1973, the Radar Spectrum Engineering Criteria were made applicable to all new radars that operate below 40,000 MHz except:

a) man-portable radars;

b) pulsed radars that have a rated peak power of less than 1 kW; and

c) pulsed radars designed to be used aboard a mobile platform (e.g., ship, aircraft or spacecraft), and whose operating frequencies are equal to or greater than 2900 MHz, and whose rated peak power is no greater than 100 kW.

The FCC has no comparable criteria for radars under its jurisdiction.

4.4 LAND MOBILE

The standards and techniques used for the management of spectrum for land mobile applications are quite diverse. Mobile communications are critically dependent on availability of frequencies for carrying out their intended purposes. The land mobile services continue to be among the largest and fastest growing of radio services. Non-government usage of mobile communications is generally closely correlated with population densities; whereas government use is more diffusely distributed on a geographical basis and is associated with agency facility location.

The techniques and standards applicable to land mobile systems include limitations on channel bandwidth, usage, real-time spectrum engineering, local coordination, new technology and sharing with television channels.

Other sections of this book have dealt with new techniques, technology, and real-time spectrum management. This one will be primarily devoted to the particulars of the standards in the government and non-government mobile services.

4.4.1 Non-Government

The non-government land mobile services fall into three principal categories: industrial, land transportation and public safety. Within these three basic groupings, there are approximately twenty different radio services. Until recently, the most important method of spectrum management was use of *block allocation*, i.e., each of the individual

services was allocated its own set of frequencies has grown, these services now share with other land mobile services on a secondary basis.

The technical standards to which these services are required to adhere are quite similar. The typical characteristics affecting use of the spectrum are indicated below:

4.4.1.1 Transmitter Frequency Stability

The stability of transmitters for the different land mobile frequency bands is as specified in Table 4.6.[4]

Table 4.6 - Frequency Stability for Land Mobile Transmitters

Frequency	Transmitter Power*	Fixed	Base	Mobile	
		>300W	<300W	≥3W	<3W
below 25 MHz		0.005%	0.01	0.01	0.02
25-50		.002	.002	.002	.005
50-450		.0005	.0005	.0005	.005
450-470		.00025	.00025	.0005	.005
470-512		.00025	.00025	.00025	.00025
806-821		.00015	.00015	.00025	.00025
851-866		.00015	.00015		

* The power of a transmitter is considered to be the maximum valid plate power at the input to the final stage as specified by the manufacturer.

4.4.1.2 Emission Limitations

The principal types of emissions authorized are A3 and F3; although under certain circumstances A2, A9, F2, and F9 may also be used. For all A3 emissions the authorized bandwidth is 8 kHz. The authorized bandwidth and frequency deviation for F3 in the bands 25-50, 50-150, 150-450, 450-470, 470-512, 806-821, and 851-866 MHz are 20 kHz and 5 kHz, respectively.

4.4.1.3 Spurious Emission

The power of any frequency removed from its assigned frequency between 50 and 100 percent should be down 25 dB; from 100 to 250 percent, down 35 dB; and when greater than 250 percent, at least 43 + 10 $\log_{10}$ or 80 dB whichever is lesser.

4.4.1.4 Power Limitations

In general, the power of a mobile station should be the minimum necessary to serve a particular area. The maximum permitted powers for various bands are indicated in Table 4.7 below:[4]

Table 4.7 - Transmitter Power Limits for Land Mobile

Frequency (MHz)	Power (watts)
1.6-6	2,000
25-100	500
100-216	600
220-470	600
470-512	1,000 (eirp)

4.4.1.5 The Band 470-512 MHz

Mobile communications are permitted to operate in this band, which is assigned on a primary basis to broadcast television. The conditions for use are as follows:

1) Transmitters must be located not more than 50 miles from the geographic centers of Boston, Chicago, Cleveland, Dallas, Detroit, Houston, Miami, Los Angeles, New York, Philadelphia, Pittsburgh, San-Francisco, or Washington, D.C.

2) Mobile units should be no more than thirty miles from their associated base station; and

3) Antenna heights should be limited in proportion to the distance from the protected UHF-TV station(s).

4.4.2 Government

The following spectrum standards apply to U.S. federal government land mobile operations in the bands 29.89-50 MHz, 150.8-174 MHz, and 406.1-420 MHz.

4.4.2.1 Transmitters

1) Frequency tolerance - the frequency tolerances are indicated in Table 4.8.[4]

Table 4.8 - Frequency Tolerances for Land Mobile Bands

Frequency MHz	Fixed & Base <10w	Fixed & Base >10w	Mobile <10w	Mobile >10w
29.89-50	0.002	0.0005%	0.002	0.0005
150.8-174	0.0005	0.0005	0.0005	0.0005
406.1-420	0.0005	0.00025	0.0005	0.0005

2) Spurious emission - the standard for government in similar to that for non-government; except that for any frequency removed from the assigned frequency by more than 250 per cent of the authorized bandwidth, the spurious emission is to be no greater than 10 µW or -50 dB + 10 $\log_{10}P$ for transmitter of greater than 10 watts and 50 µW or -43 + 10 $\log_{10}P$ for a transmitter of 10 watts or less.

4.4.2.2 Receivers

1) Sensitivity - systems should utilize the most sensitive receiver practicable for satisfactory operation.

2) Frequency tolerance - the receiver frequency tolerance is the same as that specified for the transmitter.

3) Adjacent channel selectivity and densitization -

(a) for stations having power output greater than 10 watts, the attenuation should be 80 dB.

(b) for the three bands, for stations having output power of 10 watts or less, the attenuation should be 50, 70, and 60 dB, respectively.

4) Spurious responses

(a) If transmitters have output greater than 10w: - 85 dB attenuation.

(b) If transmitters have output equal to or less than 10w: - 60 dB attenuation.

5) Intermodulation spurious responses for the three bands, then the attenuation should be:

(a) If transmitters have output greater than 10 watts: 60, 70, and 70 dB.

(b) If transmitters have output less than 10 watts, 50, 50 and 50 dB respectively.

6) Spurious responses = 80 dBW

4.4.2.3 Antennas

The OTP Manual specifies that mobile system antennas should have the following characteristics:

1) Antenna height above ground should be no greater than necessary. (Antennas in mountainous areas should be located at the lowest usable elevation, with consideration given to natural site shielding and/or gain to and from areas outside the desired service area).

2) Antenna gain should be no greater than required.

3) Directional antennas should be used for point-to-point circuits. Antenna directivity and front-to-back ratios should be optimum for the intended service.

4) Antennas with radiation patterns which most approximate the shape factor of the desired service area should be used.

4.5 BROADCASTING SERVICES[5]

This section will deal with the major broadcasting services: Standard AM, FM, and TV: the band 100-1000 MHz TV accounts for approximately 40 per cent of the allocated spectrum. The relevant Rules and Regulations of the FCC are parts 73 and 74. They contain more technical information on these services than on any other under FCC jurisdiction. This section will discuss those aspects of these regulations which impact on the use of the spectrum.

4.5.1 Standard Broadcasting (AM)

This service uses amplitude modulation in the band 535 to 1605 kHz. This band is divided into channels 10 kHz wide. Each of these is designated as being available for a particular type of coverage; e.g., clear channel, regional channel, or local channel. AM broadcasting has developed in such a way as to provide a variety of services having a wide range of technical criteria. It is the only broadcast service which actually engages in something approximating spectrum engineering. From a spectrum use standpoint, the important characteristics include power, antenna pattern and interference prohibition requirements.

Table 2.5 (Chap. 2) shows the permissible power and protected interference contours for the various classes of stations. Fig. 4.3 is used as the basis for calculating protection contours around the transmitting station. Such contours determine how far one station must be separated from another. Directional antennas are permitted.

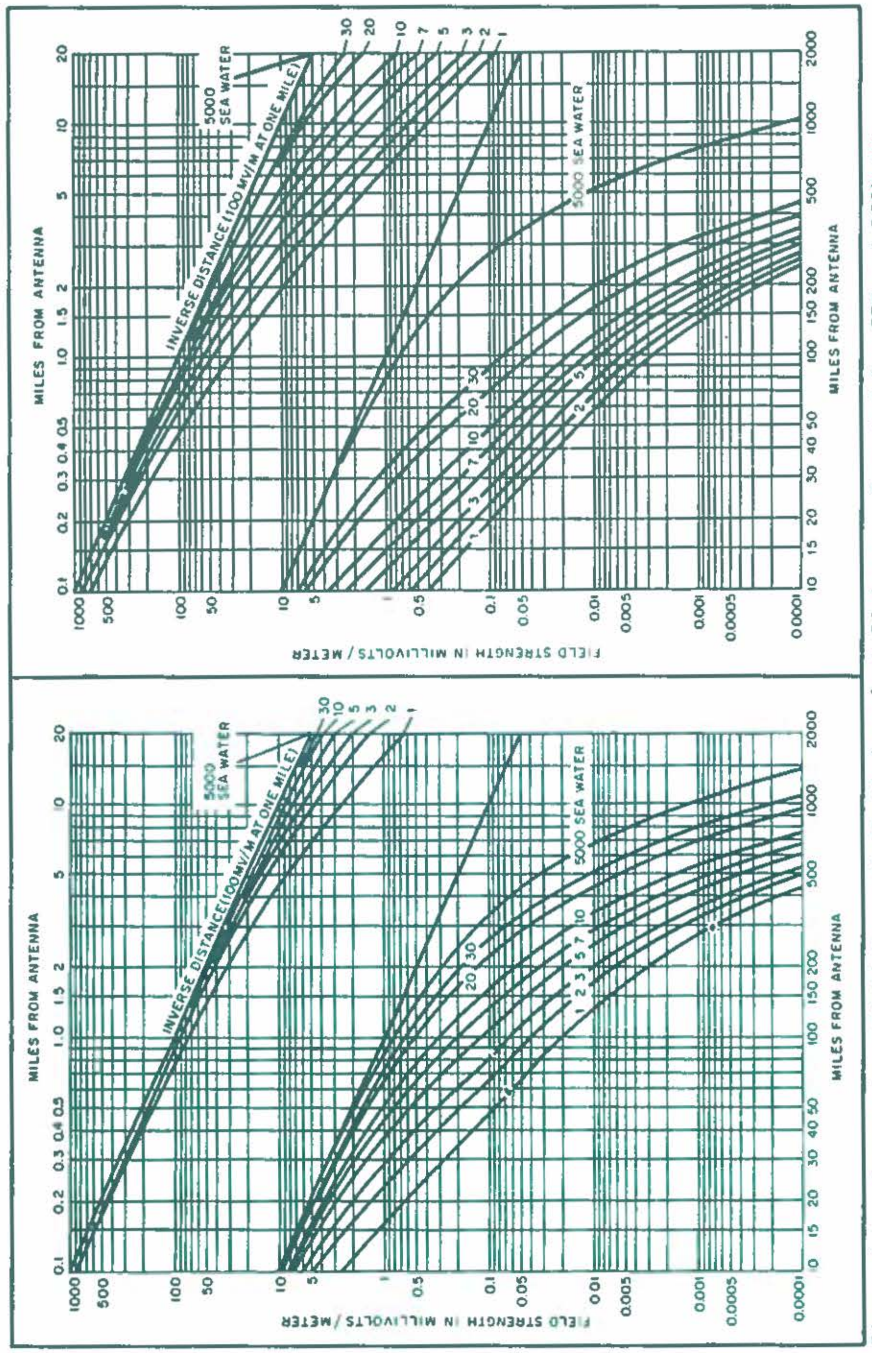


Figure 4.3 - Ground-Wave Field Strength Plotted against Distance. Computed for 550 and 1600 kHz. Dielectric Constant = 15. Ground- Conductivity Values are in millimhos/meter.

In addition, the carrier frequency must be maintained within 20 Hz of the assigned frequency.

4.5.2 FM Broadcasting

FM Broadcasting is carried out on 100 channels, 200 kHz wide, between 88.1 and 107.9 MHz. There are four classes of stations to which these channels are assigned. The type of service is predicated on power, coverage area, antenna height, and separation distances.

It is assumed that the coverage area will be omnidirectional from the transmitter location; i.e., no directional antennas are permitted. This, coupled with a specification of maximum antenna height and maximum effective radiated power, determines the maximum number of co-channel assignments possible in the United States. The four classes of stations and their permitted powers are:

Class A - primary service to small communities. The voltage is not to exceed the equivalent of 3kW effective radiated power (erp) at an antenna height of 300 ft. above average terrain (minimum effective erp is 100 watts).

Class B - Services to large communities that operate in Zone I (the northeastern part of the U.S.) or Zone IA (Puerto Rico, the Virgin Islands and California south of 50° latitude). The maximum and minimum erp's are 50 and 5 kilowatts respectively, and the maximum antenna height is 500 ft.

Class C - Large community service; but in Zone II (all other parts of the U.S., and Alaska and Hawaii). Maximum and minimum erp's are 100 kW and 2kW, and the maximum antenna height is 2000 ft. above average terrain.

Class D - noncommercial educational service, with transmitter output power no greater than 10 watts.

Table 4.9 indicates the minimum mileage separations.

Table 4.9 - Minimum Mileage Separations Between FM Stations

	Class A				Class B				Class C			
	Separation in kHz				Separation in kHz				Separation in kHz			
Class	Co-channel	200	400	600	Co-channel	200	400	600	Co-channel	200	400	600
	Min. Mileage Separations											
A	65	40	15	15	-	65	40	40	-	105	65	65
B	-	-	-	-	150	105	40	40	170	135	65	65
C	-	-	-	-	-	-	-	-	180	150	65	65

If it is desired to increase the antenna height of a Class A, B, or C station, there must be a commensurate decrease in the erp. The basis for doing this is shown in Fig. 4.4.

4.5.3 TV Broadcasting

There are four parts of the spectrum assigned to television broadcasting, making available, altogether, eighty-one 6 MHz channels. The channel number and frequency were previously discussed in Chap. 2. The spectrum use standards are similar in approach to the FM standards. For the different types of service a maximum antenna height and erp are assumed, and no directional antennas are permitted. As a result it is a simple matter to determine minimum deparation distances between co-channel and adjacent channel stations. This gives rise to an upper limit in the number of permitted TV stations. For UHF stations, this number is approximately 1200, and for VHF approximately 450.

The maximum television antenna height/power combinations for different channels are shown in Figs. 4.5 and 4.6 for the three different separation distance zones. Zones I, II, and III are characterized by different geographical features, propagation conditions and populations. The separation distances for these zones are indicated in Table 4.10.[3]

Table 4.10 - VHF-TV Station Separation Criteria

	Co-Channel (miles)		Adjacent Channel (miles)	
Zone I	170	155	60	55
Zone II	190	175	60	55
Zone III	220	205	60	55
	2-13	14-83	2-13	14-83

Zone I is northeast U.S., Zone III is a strip along the southeastern border of the U.S., Zone II is the balance of the continental U.S., Hawaii and Alaska.

There is no specified interference protection ratio, and no regulation of TV receivers. Interfering contours are established on the basis of overlapping signal contours from co-channel and adjacent channel stations.

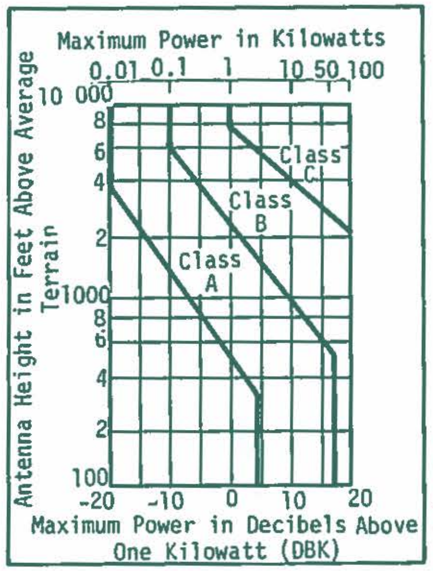


Figure 4.4 - Maximum Permissible Radiated Power as a Function of Antenna Height (From FCC Rules and Regulations, Vol. III, Part 73, p. 173; 1964)

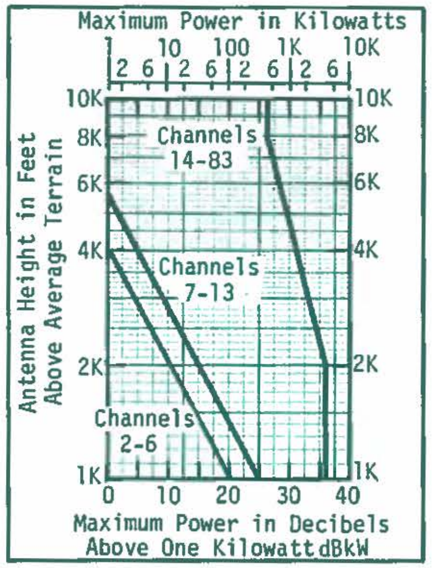


Figure 4.5 Maximum Television-Station Power Versus Antenna Height for Zone I. (From FCC Rules and Regulations, vol. III, Part 73, p. 237; 1964.)

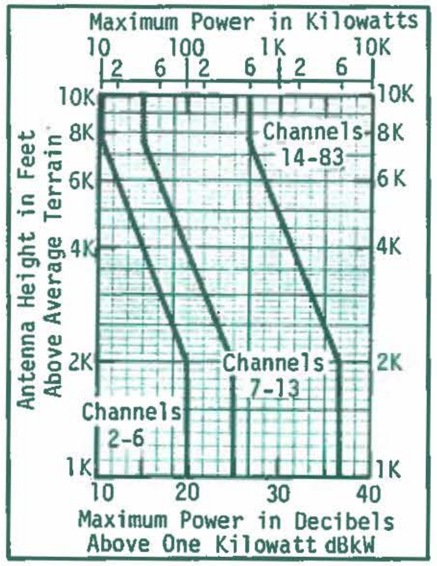


Figure 4.6 - Maximum Television-Station Power Versus Antenna Height for Zones II and III. (From FCC Rules and Regulations, vol. III, Part 73, p. 239; 1964.)

4.6 SPACE SERVICES

Space services represent the newest set of radio services. Most of them perform services which are under the jurisdiction of various government agencies and departments. As indicated previously, the spectrum standards and techniques which apply to these services were necessitated by their having to share spectrum already allocated to other services.

4.6.1 Power from the Satellite (PFD Limit)

Primary among such criteria is the amount of power which would be allowed at the surface of the earth to insure that there would be no harmful interference to existing terrestrial systems. Table 4.11 shows the flux-density limits for space[2] services sharing with different types of terrestrial services.

4.6.2 Emissions from the Spacecraft

The emissions from spacecraft are controlled in several ways in order to ensure that transmitters orbiting the earth do not cause harmful interference:

4.6.2.1 Control of Interference between Geostationary Satellite Systems and Non-Synchronous Inclined Orbit Satellite Interference

In accordance with Radio Regulation 470VA, non-geostationary space stations in the fixed satellite service are required to cease or reduce radio emissions to a negligible level. Their associated earth stations are not permitted to transmit to them whenever there is (a) insufficient angular separation between the non-geostationary satellite and (b) unacceptable interference to geostationary satellite systems.[2]

4.6.2.2 Station Keeping on Space Stations

Space stations on geostationary satellites are required to have the capability of maintaining their positions within $\pm$ 1 degree of the longitude of their nominal positions (RR470VC).

4.6.2.3 Pointing Accuracy of Antennas on Geostationary Satellites

The pointing direction of maximum radiation of any earthward beam of an antenna (intended for less than earth coverage) on a geostationary satellite is required to have the capability of being maintained within (a) 10 percent of the half power beamwidth relative to the

Table 4.11 - PFD Limits

Fixed and Mobile

Frequency Band (MHz)	Space Radiocommunication Service	Angle of arrival (δ) above the horizontal plane in degrees		
		0-5°	5-25°	25-90°
1670-1690 1690-1700 1700-1710 2200-2300	Meteorological-Satellite Meteorological & Earth Exploration-Satellite (for countries mentioned in ITU No. 354A) Space Research Space Research	-154 dBW/ m^2/4 kHz	$-154 + \frac{\delta-5}{2}$ dBW/ m^2/4 kHz	-144 dBW/ m^2/4 kHz
7300-7750 7450-7550	Fixed-Satellite Meteorological-Satellite	-152 dBW/ m^2/4 kHz	$-152 + \frac{\delta-5}{2}$ dBW/ m^2/4 kHz	-142 dBW/ m^2/4 kHz
8025-8400 8025-8400 8400-8500	Fixed-Satellite Earth Exploration Satellite Space Research	-150 dBW/ m^2/4 kHz	$-150 + \frac{\delta-5}{2}$ dBW/ m^2/4 kHz	-140 dBW/ m^2/4 kHz
21200-22000	Earth Exploration Satellite	-115 dBW/ m^2/1 MHz	$-115 + \frac{\delta-5}{2}$ dBW/m^2/1 MHz	-105 dBW/ m^2/1 MHz

Meteorological Aids

1690-1700	Meteorological and Earth Exploration-Satellite	-133 dBW/m^2/1.5 MHz for all angles of arrival

Troposcatter

1670-1700 1700-1710 2200-2300	Meteorological and Earth Exploration-Satellite Space Research Space Research	-168 dBW/4 kHz (see ITU No. 470NGA)

nominal pointing direction, or (b) 0.5 degree relative to the nominal pointing direction, whichever is greater (RR 470VG).

4.6.2.4 Control of Emissions from Space Stations

To permit satisfaction of the maximum number of frequency requirements, assignments must be capable of time-sharing to the extent practicable to preclude mutual, harmful interference. Therefore, the use of frequencies by space stations is authorized only in those cases where such stations are equiped with the ability to control emissions on and off by telecommand (RR 470V).

4.6.3 Control of Emissions from Earth Stations

4.6.3.1 Power and Direction of Maximum Radiation of Earth Stations in Certain Bands Shared with Stations in the Fixed or Mobile Service

In general, in frequency bands between 1 and 15 GHz, equivalent isotropically radiated power of earth stations in any direction towards the horizon is not to exceed the following limits:

+ 40 dBW in any 4 kHz band for $\theta \leq 0°$

+ 40 + 3 dBW in any 4 kHz band for $0° < \theta \leq 5°$

For angles of elevation on the horizon above 5°, there is no limit as to the equivalent isotropically radiated power transmitted by earth stations towards the horizon (RR 470G).

Earth station antennas for services other than the space research service are not to be employed at elevation angles of less than 3° measured from the horizontal plane to the direction of maximum radiation.

Earth station antennas for the space research service are not to be employed at elevation angles measured from the horizontal plane to the direction of maximum radiation of less than 5° for the near-earth operations, nor less than 10° for deep space operations.

4.6.4 Selection of Sites and Frequencies for Earth and Terrestrial Stations

Sites and frequencies for earth and terrestrial stations operated in frequency bands above 1 GHz which are shared with communication services are to be selected, to the extent practicable, in areas where the

surrounding terrain and existing frequency usage are such as to minimize the possibility of harmful interference between the sharing services.

These constitute the basic spectrum constraints on space services. Additional ones may be adopted at future radio conferences.

4.7 REFERENCES

1. FCC Rules and Regulations
2. International Radio Regulations; International Telecommunications Union, Geneva Switzerland.
3. Manual of Regulations and Procedures for Radio Frequency Management; Office of Telecommunications Policy, 1975.
4. Reference Data for Radio Engineers, ITT, Fifth Edition.
5. Report 224-1 (Rev.), Vol. II, Documents of CCIR, New Dehli; 1970, ITU.

CHAPTER 5

RADIO PROPAGATION, MEASUREMENT AND MONITORING

A critical factor in managing the radio frequency spectrum is an adequate appreciation of the radio environment including both its natural and man-made components. This requires an understanding of radio propagation phenomena for different modes of transmission, and the capability to measure and monitor it. This chapter is devoted to a discussion of methods concerned with these aspects of spectrum management.

5.1 RADIO PROPAGATION[1]

The success of a telecommunication system is largely dependent on how well the pertinent radio equipment has been matched to the radio environment over the radio path of concern. If this has been done optionally, then not only is the intended information transfer accomplished, but the system also has been well spectrum-engineered. This is because the quality of a radio link is dependent upon having available sufficent information to describe the radio environment through which a signal passes from transmitter to receiver. The general influence of this radio environment on telecommunication systems is illustrated in Fig. 5.1. As is apparent, there are both man-made and natural sources of electromagnetic radiation which affect the quality of the realizable signal for information transfer. Fig. 5.2 indicates the specific places where environmental factors influence the performance of a telecommunication system.

The performance of a telecommunication system is dependent on the available signal-to-noise ratio, R, at the receiver. If the noise environment can be accurately described, then a transmitter power may be specified of only sufficient strength to meet the required ratio. This results in good spectrum engineering. The signal-to-noise ratio may be expressed as:

$$R = (dB) = P_t + G_{pt} + G_{pr} - L_{bm} - N_m + Y$$

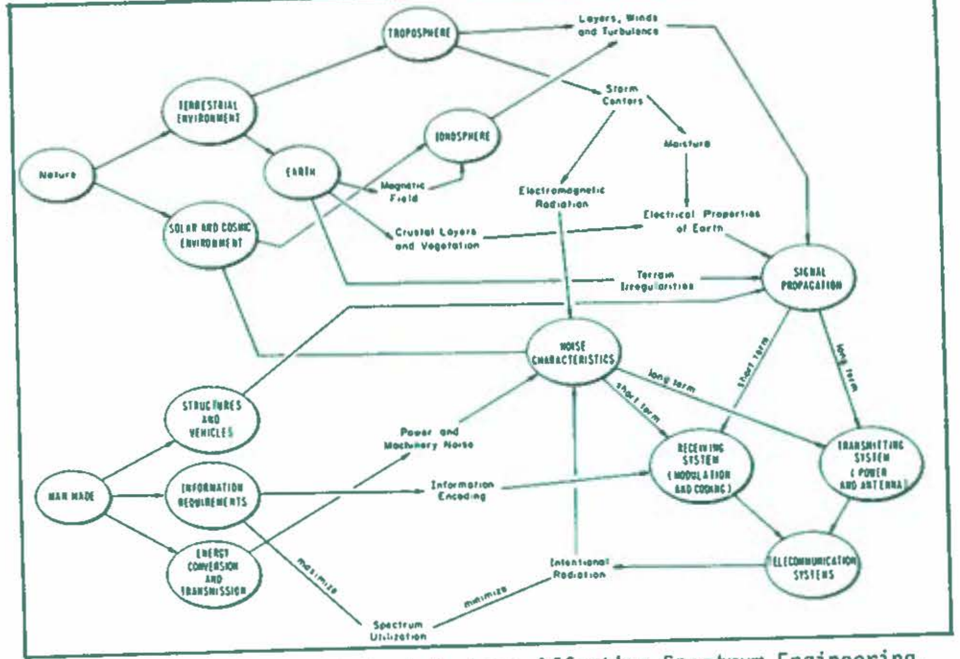


Figure 5.1 - Detailed Technical Factors Affecting Spectrum Engineering.

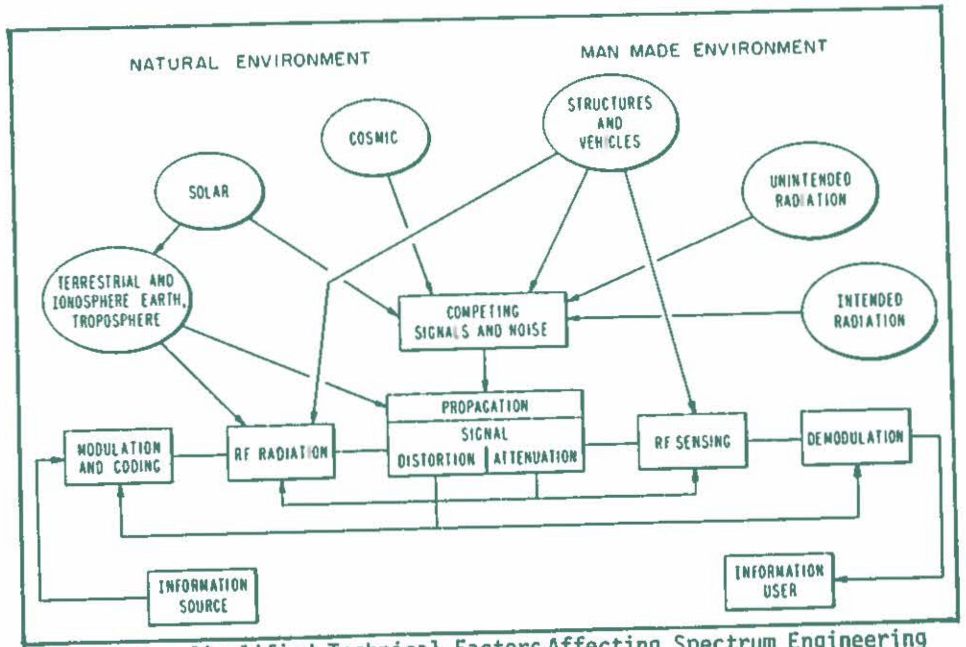


Figure 5.2 - Simplified Technical Factors Affecting Spectrum Engineering

where, P_t = power into transmitting antenna

G_{pt} = gain of transmitting antenna

G_{pr} = gain of receiving antenna

L_{bm} = the median basic transmission loss

N_m = the median effective noise

Y = factor for variability and uncertainty of prediction

Factors P_t, G_{pt}, and G_{pr} are under the control of the system designer: the others are not. From the spectrum engineering standpoint, the understanding of propagation and noise factors is concerned with defining the factors L_{bm} and N_m for different propagation modes and radio noise environments. A generalized description of the propagation modes of concern as a function of frequency is shown in Fig. 5.3.

There are three basic types of telecommunication systems from a propagation standpoint: terrestrial, scatter, and space. Most systems are terrestrial. Signals in these systems are governed by the propagation paths between transmitter and receiver. The signals which travel via the various paths are quite different. Groundwave propagation, one form of terrestrial transmission, is illustrated in Fig. 5.4. Direct and ground-reflected waves together are the space wave. A diffracted wave is called a surface wave. Generally, the groundwave provides the most stable communications; since the direct wave, when alone, is usually stable.

In general, space communications are governed by free space transmission loss. Since they involve only a direct wave, their loss is dependent only on distance and frequency.

Finally, there is a class of telecommunications which is accomplished by taking advantage of the reflective properties of the electromagnetic environment; namely, the ionosphere and the troposphere. The ionospheric wave geometry is shown in Fig. 5.5.

5.1.1 Terrestrial

For terrestrial systems, it is the earth and its atmosphere which have significant effects on the received signal. The atmosphere has two effects on propagated signals: (1) waves are refracted from straight line propagation; (2) waves are attenuated. The presence of the earth also has two effects; one, due to its curvature, the other, the attenuation of waves reflected from it, or propagated along it.

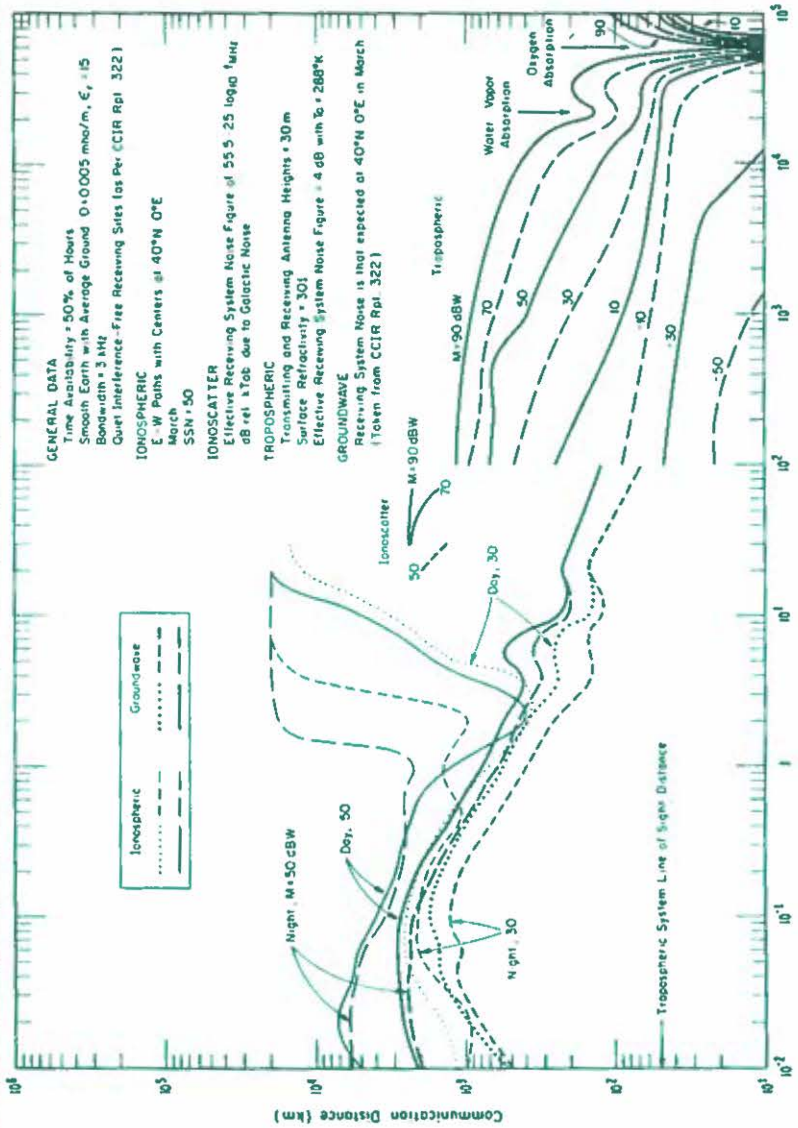


Figure 5.3 - Typically Predominant Transmission Modes

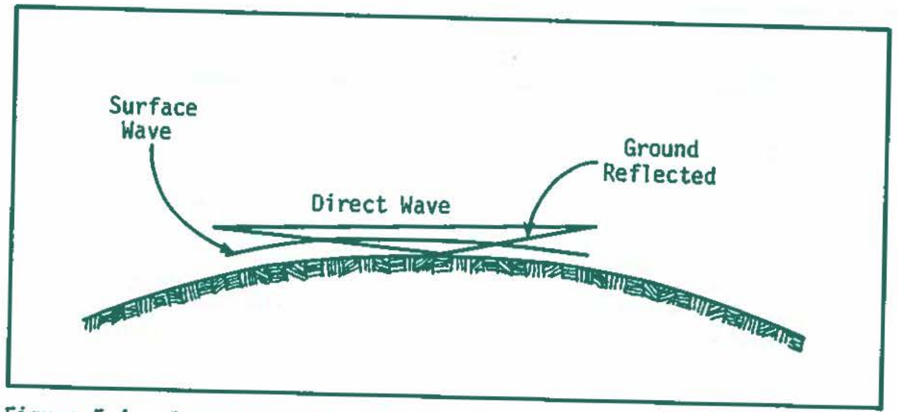


Figure 5.4 - Groundwave Transmission Modes.

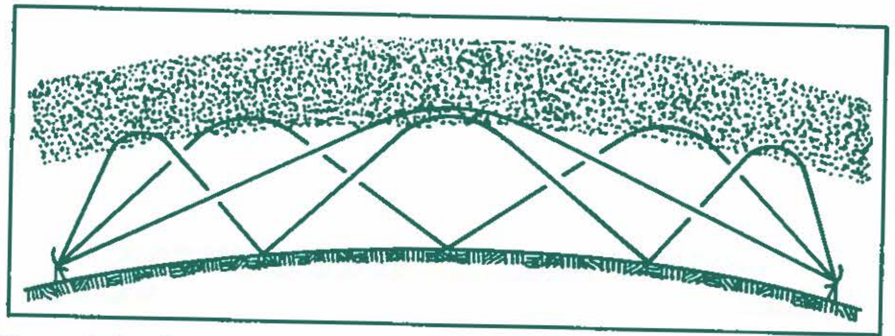


Figure 5.5 - Ionospheric wave geometry.

5.1.1.1 Atmospheric Refraction

The amount of refraction of a radio wave is dependent on the rate of change of refractive index of the atmosphere as a function of height. If the refractivity is positive, the wave will be bent away from the earth. This is measured in earth radii. Fig. 5.6 shows effective earth radius as a factor of surface refractivity. Typical minimum monthly mean surface refractivity values are shown in Fig. 5.7.

5.1.1.2 Atmospheric Attenuation

The attenuation of a radio wave caused by the atmosphere, as a function of frequency, is shown in Fig. 5.8. The attenuation is greater for waves that spend a longer time in the most dense part of the atmosphere. In addition, rain can attenuate radio signals as shown in Fig. 5.9.

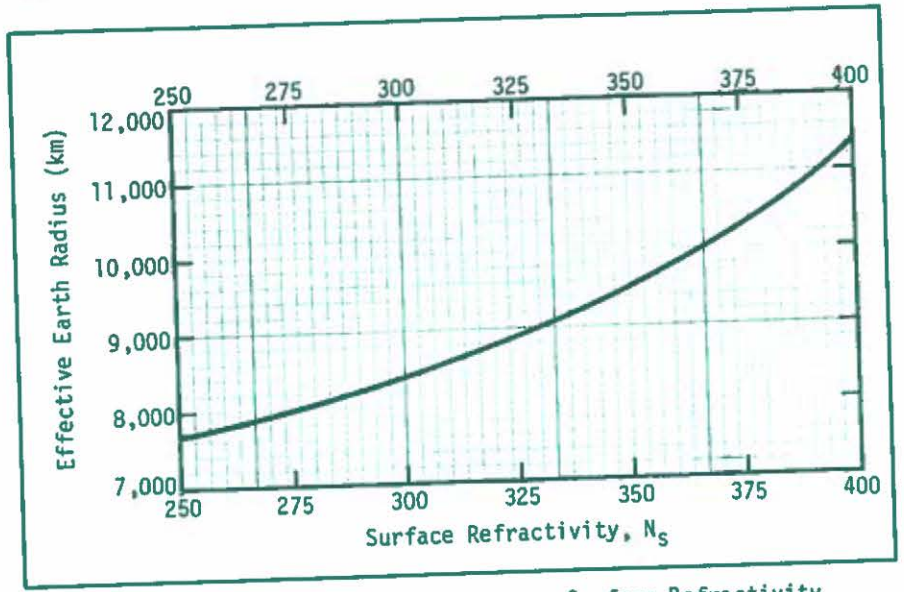


Figure 5.6 - Effective Earth Radius versus Surface Refractivity.

5.1.1.3 Ground Reflection

Ground reflection reduces the distance over which line-of-sight waves can be received. The loss depends on the angle of incidence and polarization of the wave with the earth. This loss for horizontal polarization is shown in Fig. 5.10.

5.1.1.4 Conductivity Losses

The losses in waves which propagate close to the earth, are shown in Fig. 5.11, for different frequencies. These are related to a smooth flat, perfectly conducting earth. The higher the frequency, the higher the loss.

5.1.2 Ionosphere/Troposphere

5.1.2.1 Ionospheric Refraction

The ionosphere can be used as a means of propagation from below 10 kHz to between 30 to 50 MHz. The nature of this communication path is governed by changes in the ionosphere. Propagation is usually considered to be via groups of rays which are alternately reflected from

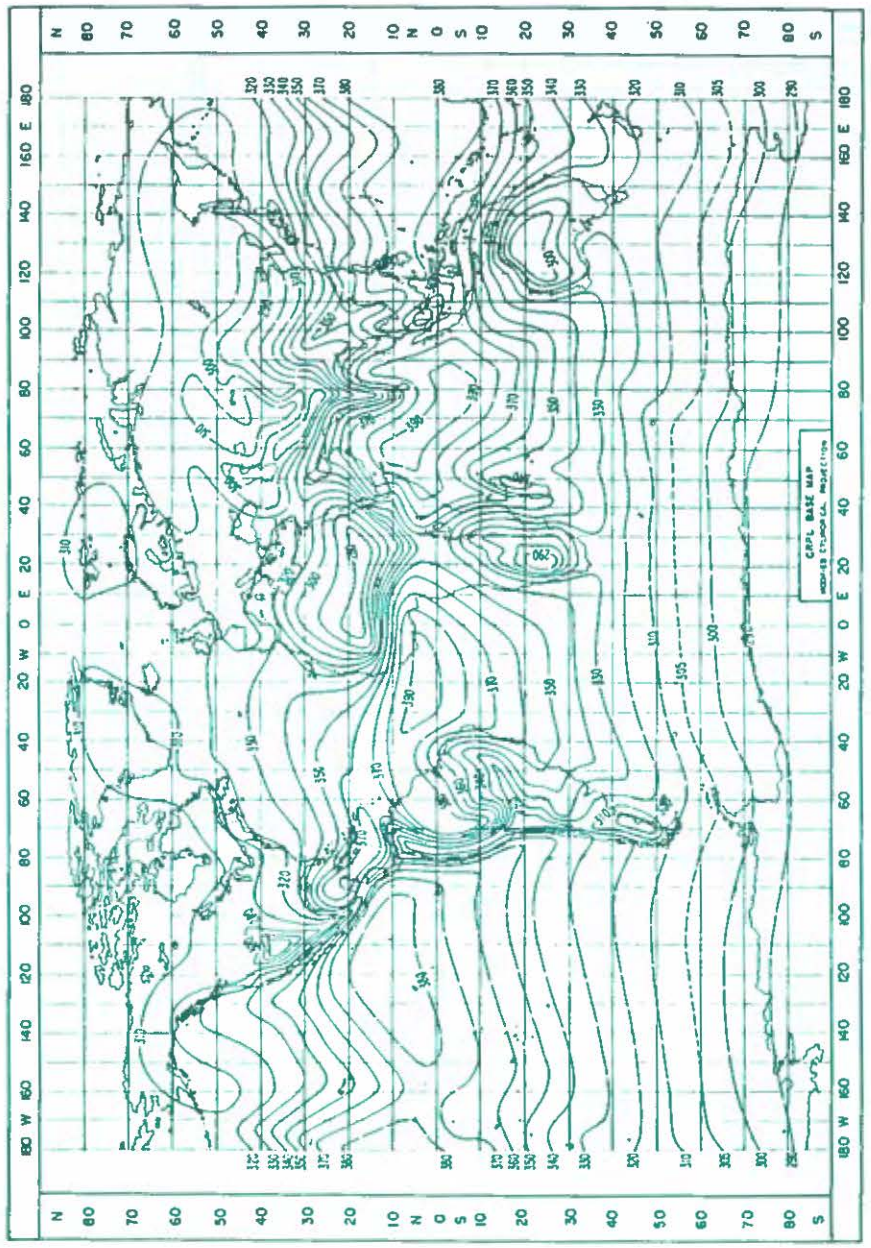


Figure 5.7 - Minimum Monthly Mean Surface Refractivity Values Referred to Mean Sea Level, $\bar{N}_s$.

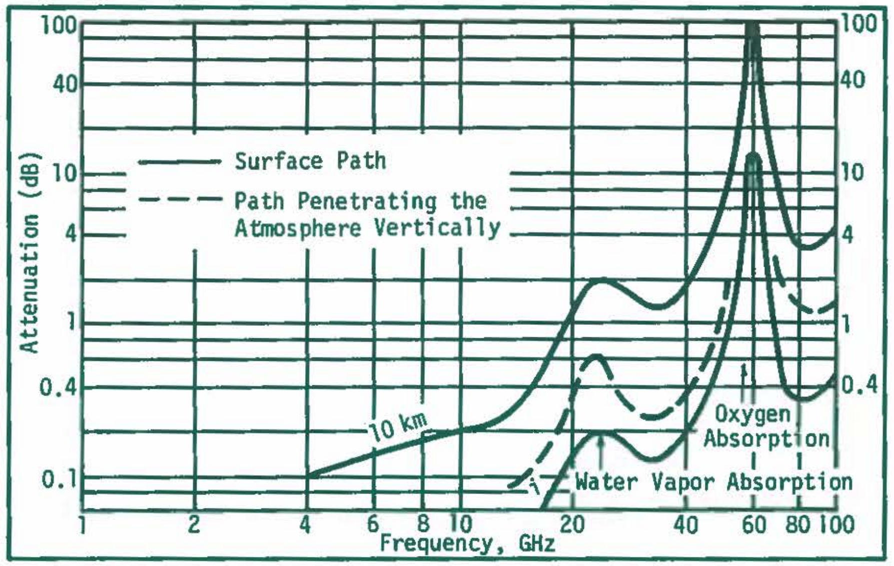


Figure 5.8 - Atmospheric Attenuation.

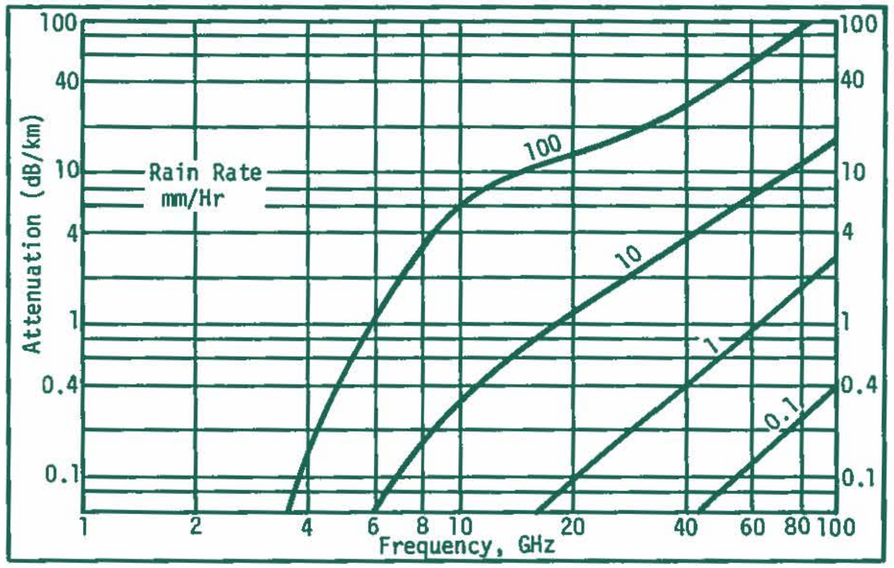


Figure 5.9 - Rainfall Attenuation.

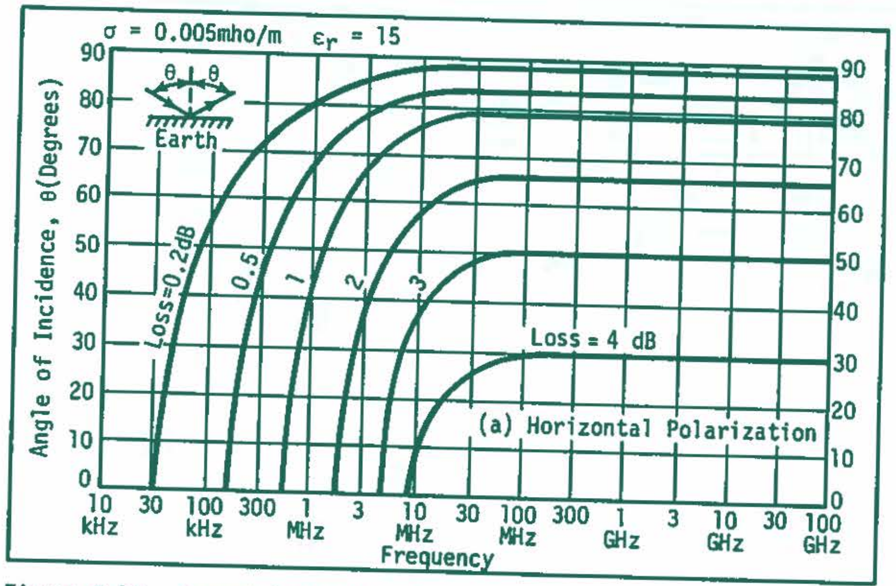


Figure 5.10 - Ground Reflection Losses

the ionosphere and the earth. There is a frequency below which waves will be returned to the earth, regardless of the path distance. This frequency is a function of the ionospheric characteristics. The useful path-length/frequency relationship can be obtained from charts such as that in Fig. 5.12.

5.1.2.2 Ionospheric Attenuation

This is attenuation due basically to the roughness of the ionosphere.

5.1.2.3 Scattering

The scatter geometry is shown in Fig. 5.13. The loss relationship for ionoscatter and troposcatter are shown in Figs. 5.14 and 5.15 respectively. This mode of propagation permits the reception of signals over relatively long distances. Troposcatter scattering is useful for distances from 100 km to 1000 km, and ionospheric scattering from about 800 km to 2200 km.

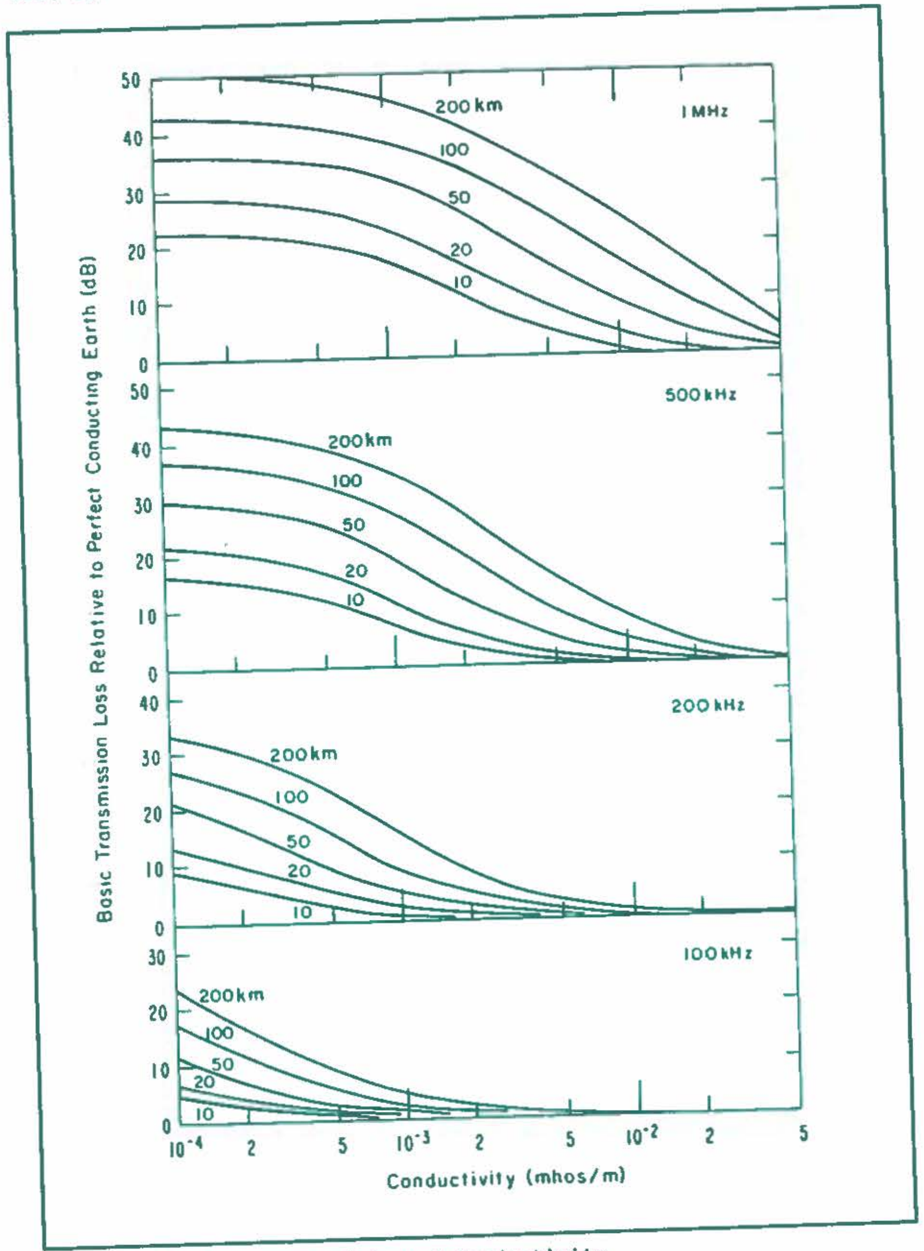


Figure 5.11 - Influence of Ground Conductivity

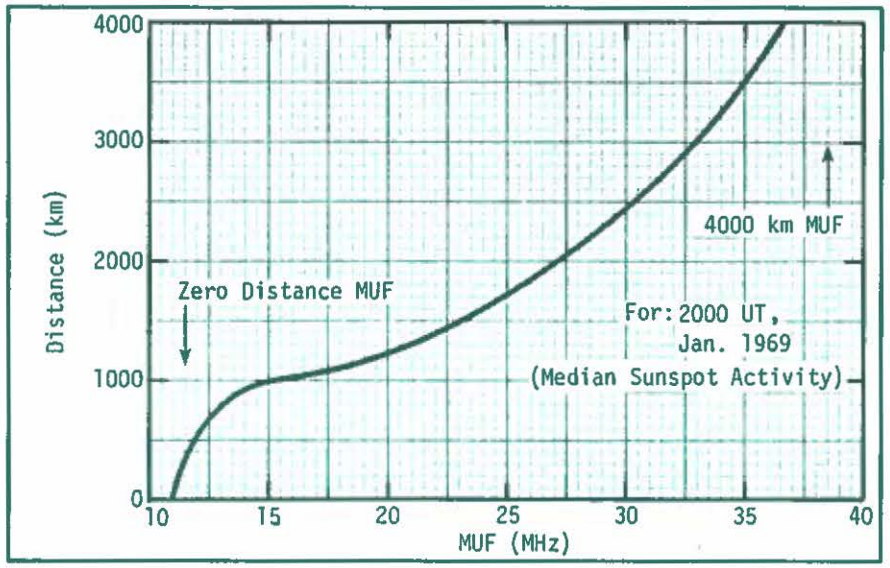


Figure 5.12 - MUF-distance Relationship.

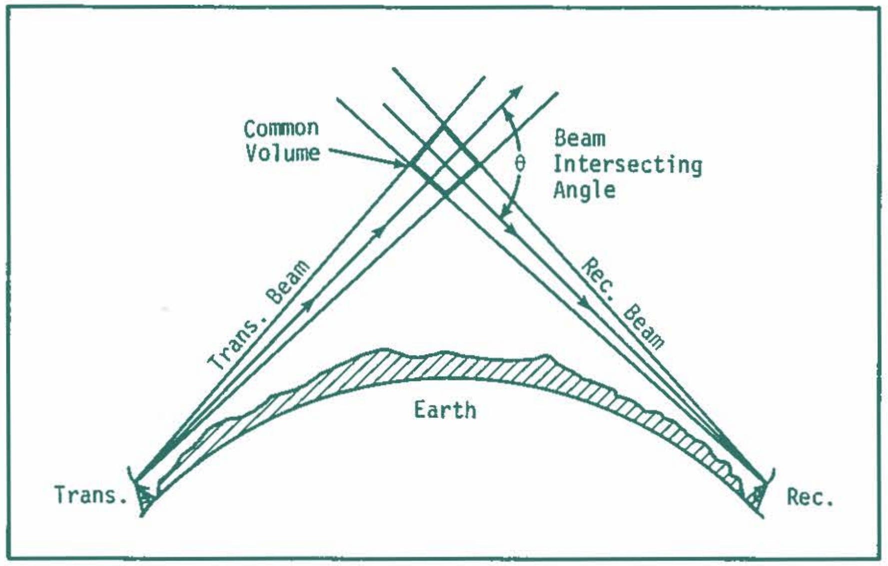


Figure 5.13 - Scatter-mode Geometry

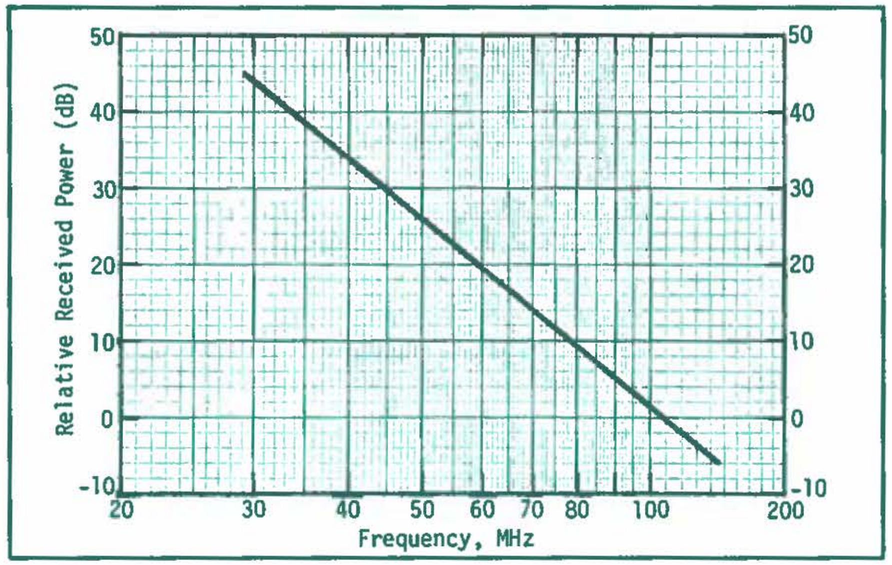


Figure 5.14 - Ionoscatter Frequency Dependence

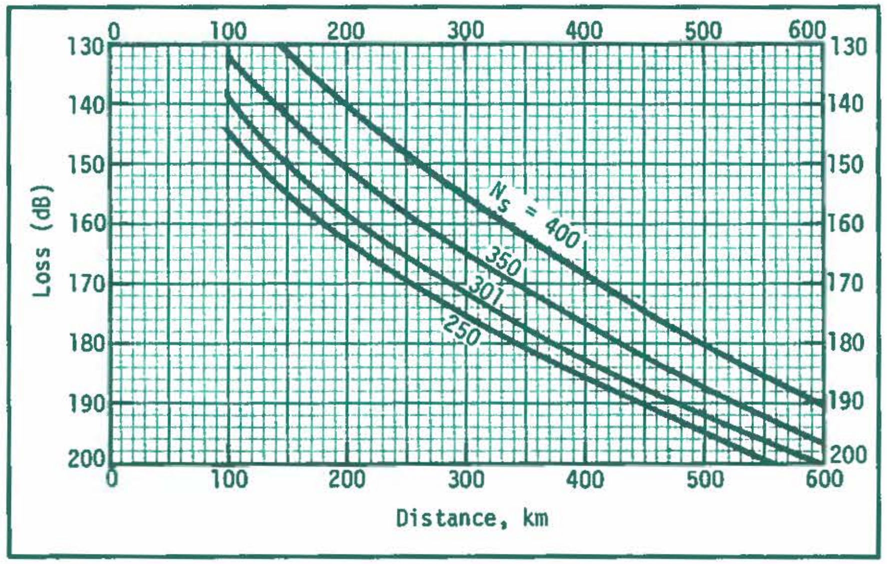


Figure 5.15 - Troposcatter Loss (Smooth Earth).

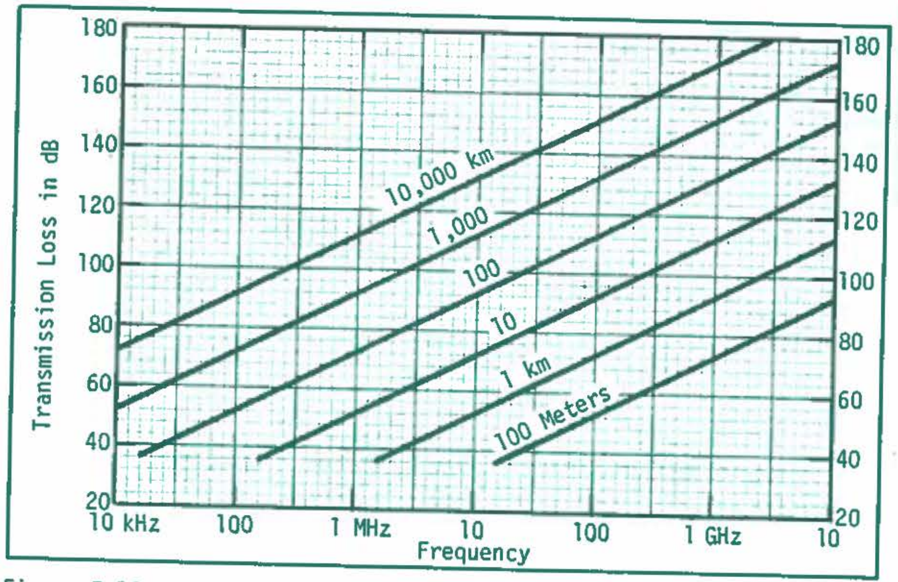


Figure 5.16 - Free-Space Transmission Loss.

5.1.3 Earth-Space Transmission

This mode of transmission is governed primarily by free space attenuation. Fig. 5.16 shows this loss as a function of frequency. It is essentially a line-of-sight transmission. The primary band of interest is 100 MHz to 20 GHz.

5.2 RADIO NOISE

There are two classes of noise--natural and man-made. The predominant sources of natural noise are electrical storms and galactic sources. Man-made noise is from either unintentional radiation such as power lines and vehicles, or intentional radiation from telecommunication transmitters (interference). Fig. 5.17 shows the distribution of natural noise with frequency. The levels generally decrease with increasing frequency. The characteristics of man-made noise are more varied than those of natural noise. Only *best-estimates*, based on limited data, have been utilized to date. An example of man-made noise levels, for different environments, is shown in Fig. 5.18. The above represents two basic propagation and noise mechanisms that must be accounted for when designing a radio system. The more accurately and conscientiously they are applied, the more reliable will be the circuit, and the better use made of the spectrum.

5.3 MEASURING/MONITORING (COMPATIBILITY, USAGE, COMPLIANCE)

This section describes the newly developed methods and techniques being used by the Office of Telecommunications (OT) in support of the Telecommunications Policy (OTP), which are providing an increasingly important tool for national spectrum management.

Critical to effective engineering of the use of the radio spectrum, is an ability to have hard evidence to provide real data for use in the analytical procedures associated eith the technical, operational, and planning aspects of spectrum management. The OTP, in 1971, proceeded to develop and implement such a capability. It was predicated on a cost/benefit analysis performed by the Stanford Research Institute; *A Spectrum Measurement/Monitoring Capability for the Federal Government.*[2] This facility was to be mobile, flexible, and sophisticated in the kinds and types of tasks it could perform. In particular, it had to be able to perform tests involving usage, compliance and compatibility. Specifically, the system is to:

(a) Determine whether Federal Government radio installations are operating on authorized frequencies, and fully in accordance with all applicable regulations.

(b) Provide information necessary to prevent or resolve instances of radio interference between two or more radio frequency users.

(c) Assist in determining whether new usage can be accomplished in a particular frequency band in a particular location[3].

The initial system being implemented by OTP is capable of carrying out measurements at various frequencies, signal powers of analyzing and storing signal data, and displaying them visually or recalling them from magnetic tape. The heart of the system is a computer-

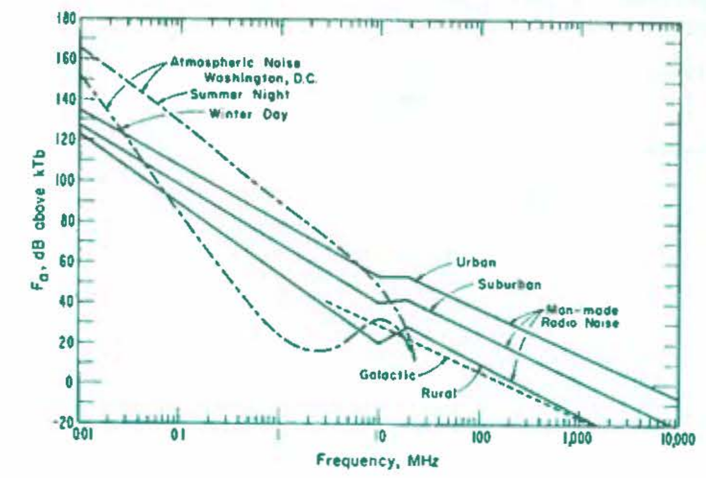


Figure 5.17 - Noise Levels

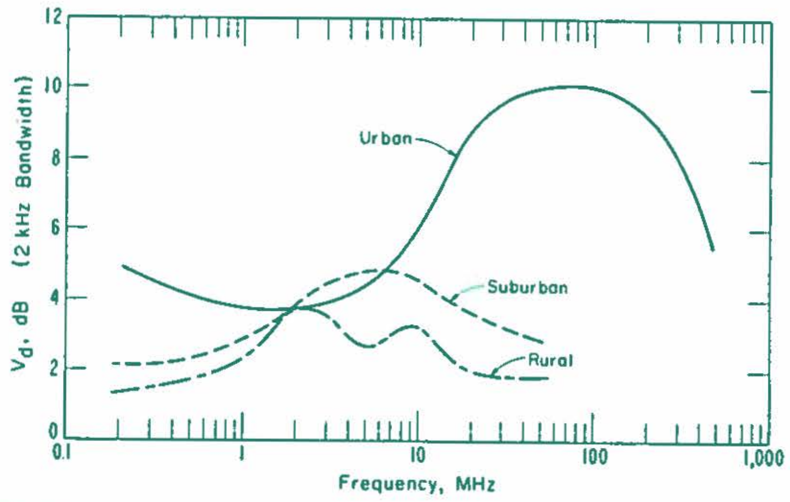


Figure 5.18 - Noise for Different Environments

controlled spectrum analyzer. The receivers of the system cover the frequency range from 108 MHz to 12 GHz.

Fig. 5.19 shows the Spectrum Measurement System (SMS). The system is composed of three major subsystems.

- Antennas
- Receiver and demodulator
- Command and data processing.

The antenna configuration is shown in Fig. 5.20. The subsystem consists of the following arrays: a 108-1000 MHz array, composed of three vertically polarized discone antennas covering the ranges 108-215 MHz, 215-420 MHz, and 420-1000 MHz respectively; a 0.15-4 GHz array, consisting of four left-hand and four right-hand circular polarized conical helix antnenas; and a 4-12 GHz array, composed of four left-hand and four right-hand circular polarized cavity-backed spiral arrays.[4] Fig. 5.21 is the receiver/demodulator block diagram. The major output of the system is digitized video from the receiver. The performance characteristics are given in Table 5.1. The receiver is fully programable from a mini-computer which is part of the command and data processing subsystem also shown in this figure. The processing equipment consists of a keyboard, a printer, a CRT, a 3-deck magnetic tape cassette unit, a 9-track magnetic tape transport and an optical punched-tape reader.

As indicated previously, this facility accumulates three types of data: occupancy (usage), compliance and compatibility.

5.3.1 Occupancy

The SMS is used to obtain temporal and spectral occupancy at a single location. An example of the type of results which may be obtained using the automated collection of data is shown in Fig. 5.22. These results are derived from analyses of measurements made over specified periods of time.

5.3.2 Compliance

This function concerns ascertaining whether or not assigned communication-electronic equipments are conforming to the Technical Standards of the OTP Manual. The kinds of measurements which are carried out are indicated in Table 5.2. Typical data obtained in connection with this activity are indicated in Fig. 5.23.

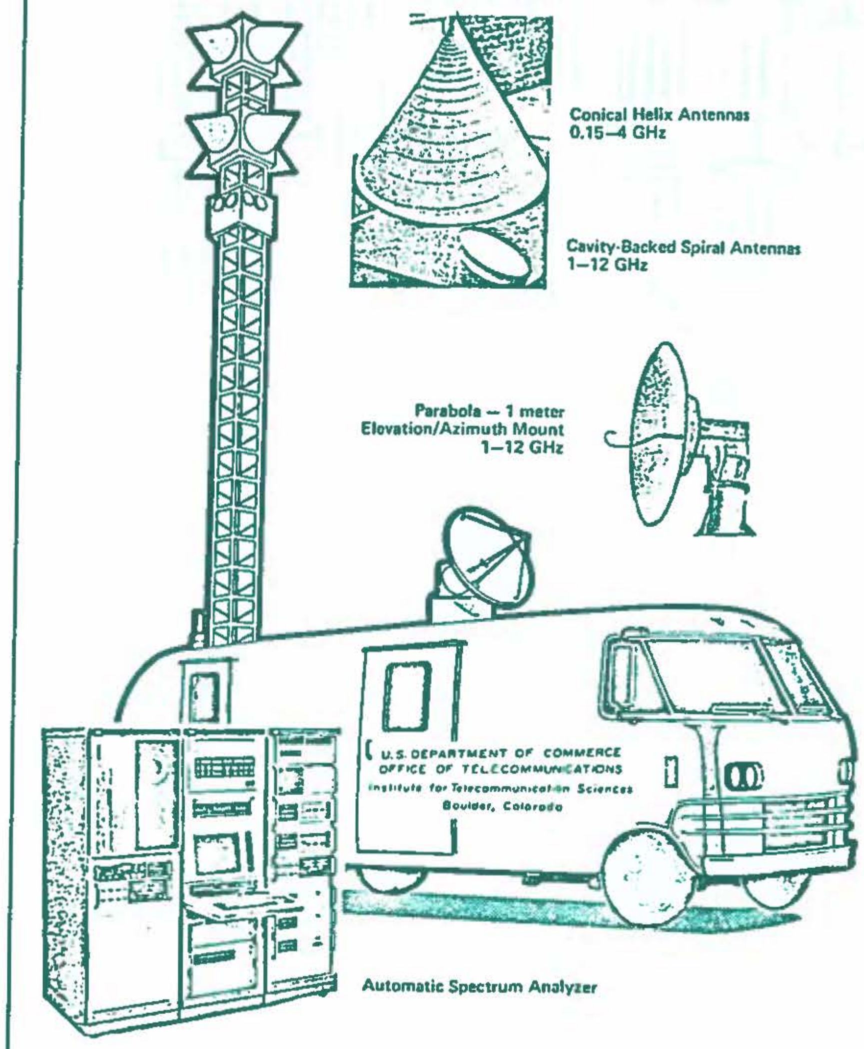


Figure 5.19 - Mobile Spectrum Monitor

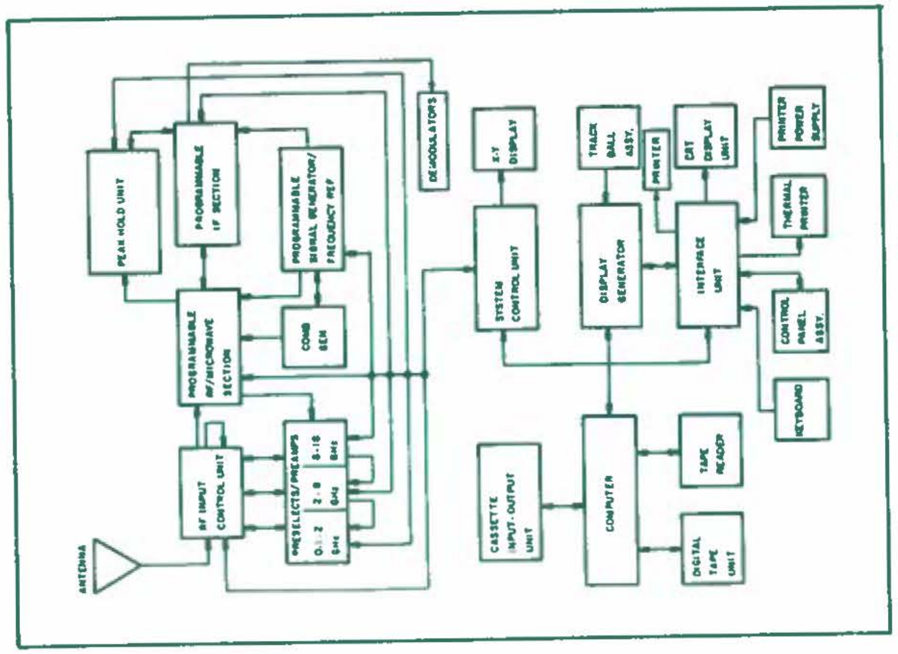


Figure 5.21 - Receiving System Functional Block Diagram

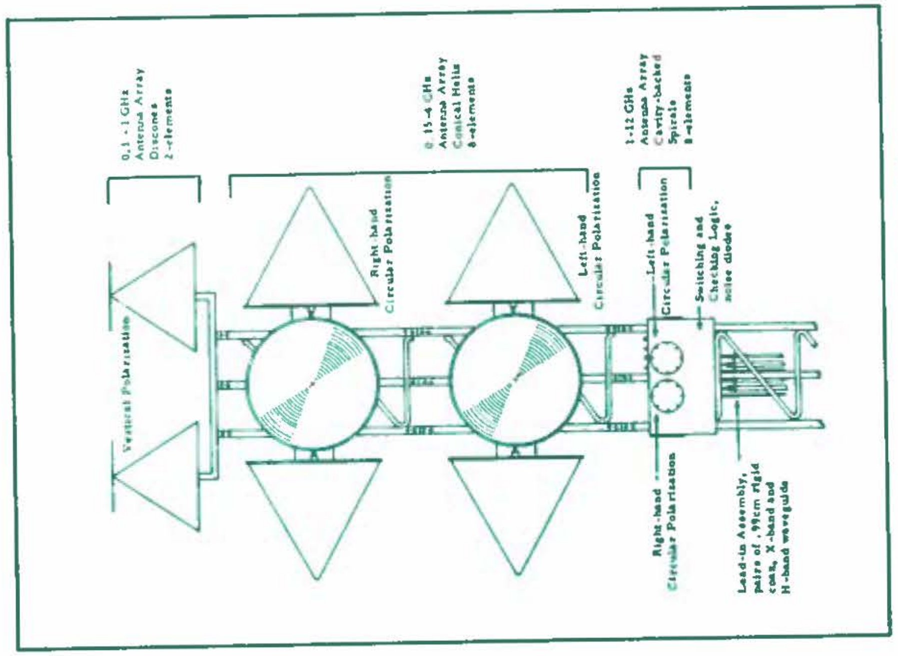


Figure 5.20 - Antenna Array Configuration On 10-Meter Tower

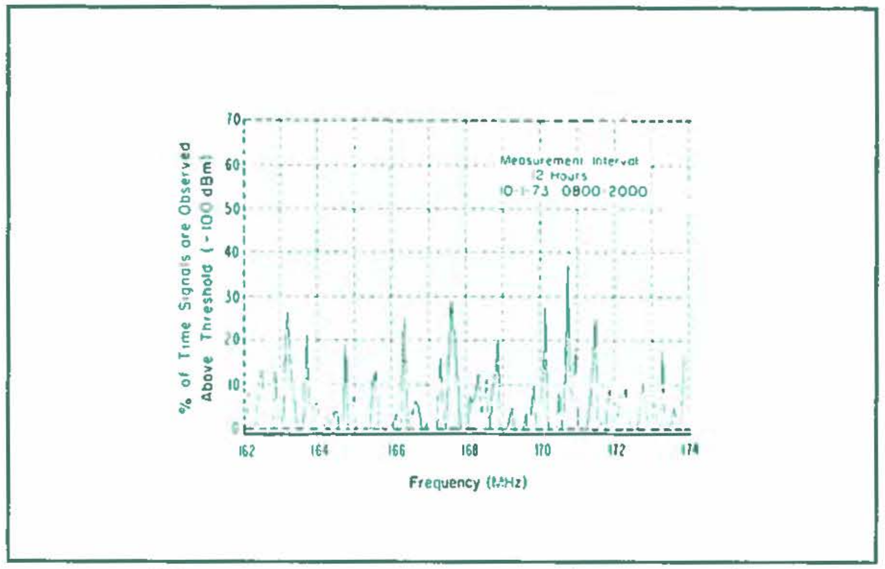


Figure 5.22(a) - Channel Occupancy, Temporal (Assumed Data)

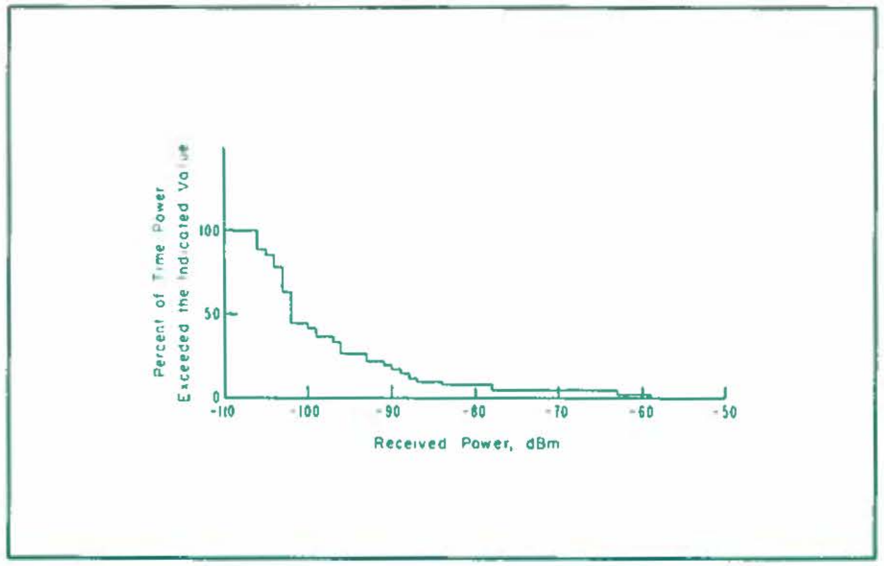
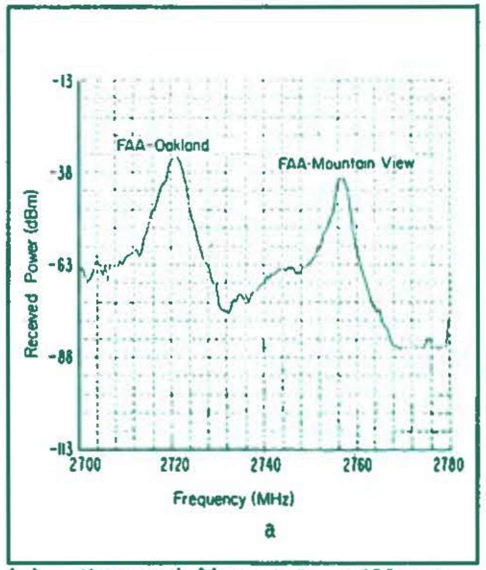
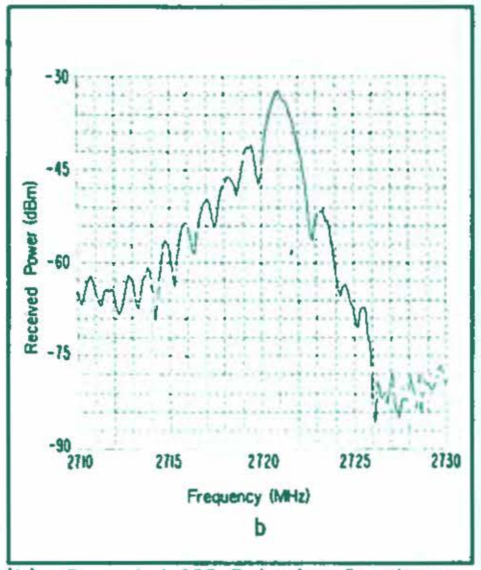


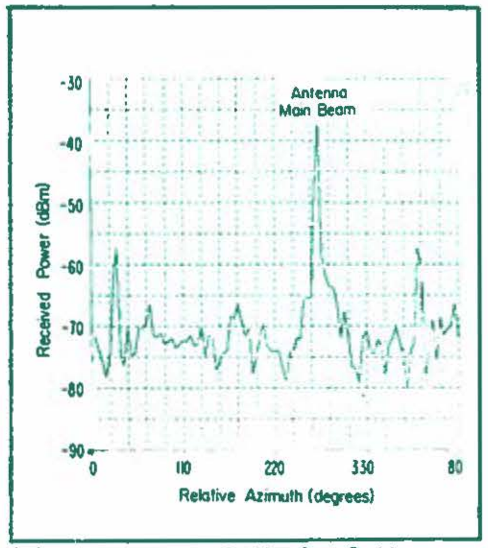
Figure 5.22(b) - Cumulative Distribution of Received Power for One Channel (170.355 MHz)



(a) - Measured Airport Surveillance (ASR) Emission Spectrum at San Francisco, California



(b) Expanded ASR Emission Spectrum



(c) ASR Antenna Radiation Pattern

Figure 5.23-Compliance Measurements

Table 5.1 - OT Spectrum Monitoring Receiver Characteristics

1. Tuning Time Δf < 10% of band = 5.8 msec Δf = full band = 7.4 msec Δf = 10 MHz-18 GHz = 96 msec	2. Tuning Accuracy 0.5 -50 MHz ± 266 Hz 0.05 - 4 GHz ± 762 Hz 4 - 12 GHz ± 2880 Hz
3. Selectivity (60/3 dB BW) Bandwidth (kHz) Ratio dB 2000 - 1000 3:1 60 300 - 10 20:1 65 3 - 0.01 11:1 50	4. Relative Amplitude Accuracy (30 MHz) 0 - 40 dB ± 0.04 dB 40 - 60 dB ± 0.06 dB 60 - 70 dB ± 0.08 dB
5. Intermodulation Distortion (3rd Order) for 2 Signals Separated 1 MHz Freq. (GHz) Signal Level (dBm) 3rd IM (dB) 0.5 - 2 -53 65 2 - 4 -54 70 4 - 8 -53 56 8 - 12 -62 53	6. Sensitivity (0.1 kHz BW) 10 - 500 MHz -145 dBm 0.5 - 2 GHz -140 dBm 2 - 4 GHz -143 dBm 4 - 8 GHz -134 dBm 8 - 12 GHz -136 dBm

5.3.3 Electromagnetic Compatibility

The automated measurement capability described herein contributes to improved EMC in several ways: a) improved occupancy and compliance information; b) confirmation and validation of analytical techniques used to predict potential EMC situations e.g., propagation and noise data; c) and confirmation of analyses concerned with specific EMC situations. In this regard, automated measurements allow verification of any specific statistical parameter of a situation for which predictions have been made.

The automated capability offers great versatility in the acquisition of data to achieve the objectives outlined in the three areas indicated above.

Table 5.2 - Compliance Parameters

Parameters	Measurement Category	Notes
RADAR		
Emission Bandwidth	Direct	1. Must be able to get in main beam at 1 n.m.
Radiated Power (ERP)	Indirect	2. Must be able to get in main beam.
		3. Must use propagation model to complete.
Antenna Pattern Relative Absolute	 Direct Indirect	Note 2, 3 above
Frequency Stability	Direct	
Tunability	No	
Spurious Radiation Relative Absolute	 Direct Indirect	Note 2 above
Selectivity	No	
COMMUNICATIONS (Land Mobile)		
Frequency	Direct	
Frequency Deviation	Direct	
Receiver Charact.	No	
Spurious Emissions Relative Absolute	 Direct Indirect	
Transmitter Power	Indirect	4. Special case. Requires knowledge of transmitter location and propagation path characteristics.

5.4 FCC REGIONAL SPECTRUM MANAGEMENT

In the non-Government sector, the FCC, with urging by the Congress, the JTAC, and the Land Mobile user community, undertook an experiment in Regional Spectrum Management. The basis for this experiment was an analysis by SRI[5] indicating that the Land Mobile frequencies under the FCC's jurisdiction were not optionally distributed. To rectify the situation, this study recommended that:

(1) The Commission should establish regional spectrum management centers;

(2) The regional centers should have the capability to: monitor the spectrum, provide liaison with users, process applications, calculate interference, and check applicants' proposed powers against that required for coverage of a particular service area; and

(3) The Commission should obtain monitoring facilities to check the occupancy of the land mobile frequencies in order to rectify imbalance of usage.

The Chicago area was chosen for the pilot project to test the concepts of Regional Spectrum Engineering.

The express purpose of this effort is to improve the use of the 2,000 channels in the bands 25-50 MHz, 150-174 MHz, and 450-470 MHz. The principal tools to accomplish this include:

(1) Monitoring capability to determine Land Mobile Spectrum Occupancy;

(2) Updated and expanded data bases sufficient for interference calculations and frequency assignments; and

(3) A computerized assignment program.

5.4.1 Monitoring Capability

The monitoring capability consists of several monitoring van, capable of taking data throughout the Chicago area. The Chicago area is considered to be a square one hundred and fifty miles on a side. The equipment is similar to that used in the OT van described in the previous section. The basic characteristics are indicated in Table 5.3.

5.4.2 Software

The associated computer capability at the Regional Center has been programmed to perform the following functions for each new applicant:

Table 5.3 - Characteristics of FCC Chicago Monitoring Van

SPECTRUM MONITOR CHARACTERISTICS
Sensitivity at 10 kHz Bandwidth
25-50 MHz -125 dBm 50-512 MHz - 120 dBm
Intermodulation Rejection - 3rd Order; 2 Signal
70 dB, or greater with two -40 dBm input signals
Dynamic Range
75 dB
Scan Rate at 10 kHz Bandwidth
3.7 ms per channel
-60 dB Bandwidth for 10 kHz - 3 dB Bandwidth
30 kHz
Data Output
Digital Tape

(1) Check each application for FAA or broadcast coordination requirements.

(2) Access the Frequency Availability List to identify those with low occupancy for given applicant.

(3) Compare applicant power with required S/N ratios throughout service area.

(4) Identify possible interfering stations already on the air, such as:

(a) Checks for adjacent channel interference
(b) Checks for 3rd and 5th order intermodulation interference.
(c) Co-channel interference.

5.4.3 Operation

The day-to-day operation of the Regional Management Center involves coordination with local authorities, continuous monitoring of the radio environment and selection of frequencies for applicants.

The data base, upon which the regional assignments are established, is derived from occupancy measurements taken in a grid of monitoring sites five miles apart throughout the regional area. The sites are visited by the monitoring van on a randomly-sampled basis. This provides data independent of cyclical natural phenomena and artificial changes in utilization patterns. At each site a monitoring period lasts for intervals of eight hours to three days. The several thousand channels are sampled in 17 blocks of 140 channels each.

Data is obtained in five-minute intervals and may be displayed in a fashion such as that in Fig. 5.24.

Fig. 5.25 depicts a typical five-minute average occupancy for a single channel. These data are combined and used as the basis for channel assignments. For co-channel interference analysis, time vs. frequency plots, such as that in Fig. 5.26, is used to determine the minimum number of transmitters operating on a particular channel. This is possible because transmitters will in general produce signals of differing amplitude at the monitor. These plots can also be examined to determine whether the transmitters are being operated simultaneously; and are, therefore, candidates for co-channel interference analysis.

In summary, a system comprising computers, analytical techniques, and monitoring-facilities, is being exploited to provide a more efficient use of spectrum. These techniques are particularly useful for mobile services because of the types of services they provide.

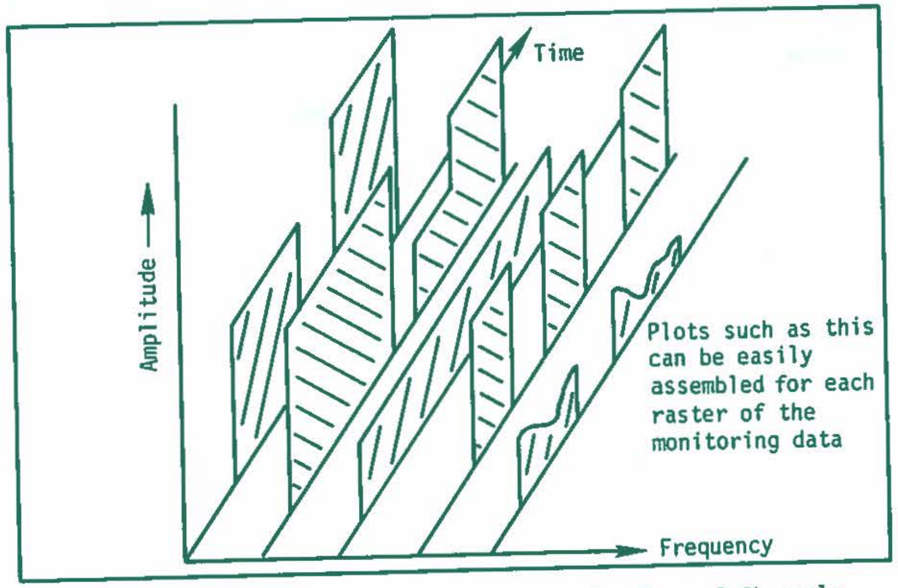


Figure 5.24 - Time/Frequency/Amplitude Plots for Several Channels

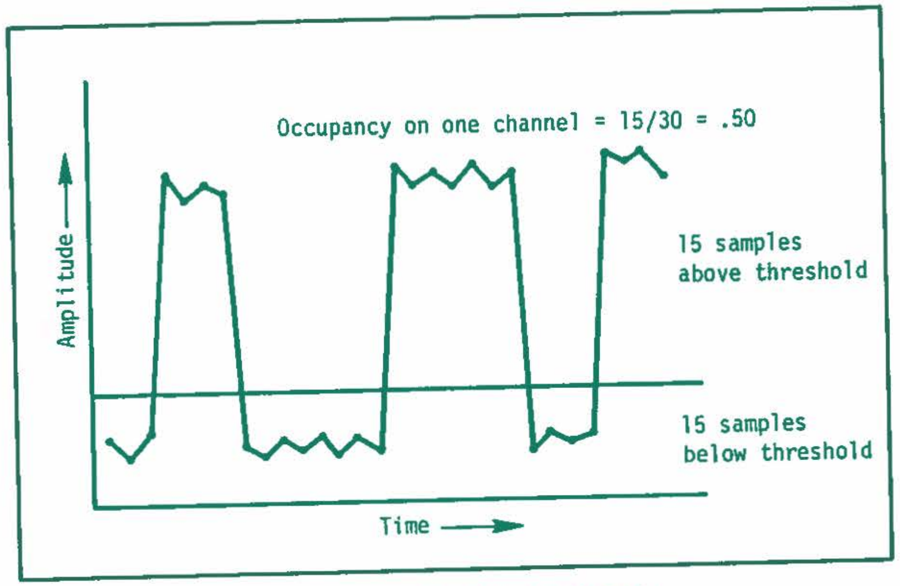


Figure 5.25 - Average Occupancy for Single Channel

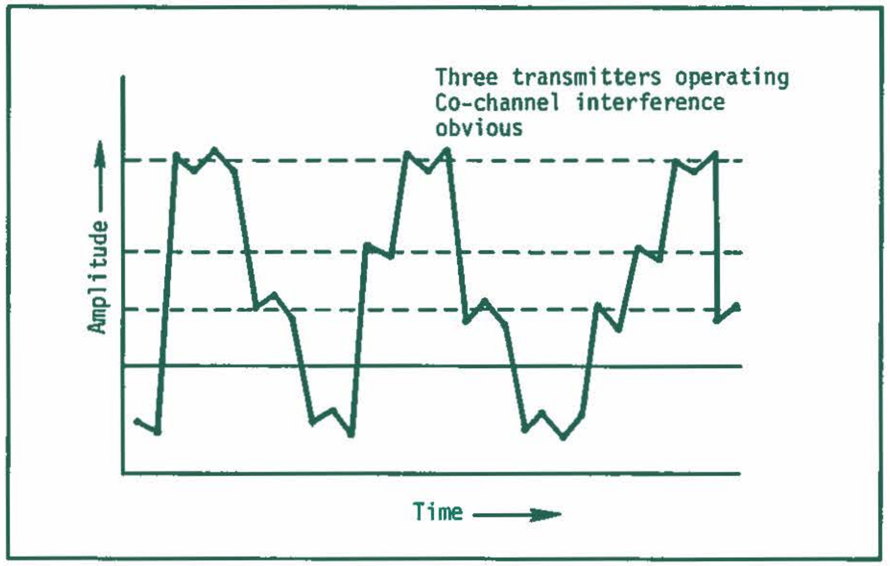


Figure 5.26 - Interference Occupancy Plot

5.5 REFERENCES

1. "Radio Channel Characteristics", Institute for Telecommunication Sciences, Office of Telecommunications, Department of Commerce.

2. A Federal Spectrum Measurement/Monitoring Capability for the Federal Government, Stanford Research Institute, 1973.

3. OTP Order No. 9 (Basis for Use of OT Measuring/Monitoring Van).

4. Proceedings of Spectrum Measurement Symposium, NASA/Goddard Space Flight Center; Oct. 1973.

5. "National and Regional Spectrum Management"; Stanford Research Institute; 1972.

CHAPTER 6

ANALYSIS TECHNIQUES

The previous chapters have dealt with the operational, technical, and planning methods of spectrum management. Associated with these have been a variety of newly-developed techniques which have influenced the decision-making processes in each of these areas. The quality of the decision making, and therefore the quality of the management, is dependent upon the analytical capabilities utilized. This chapter is devoted to a description of these techniques and their application.

6.1 SPECTRUM UTILIZATION CRITERIA

This section discusses those methods and metrics in being, and those being developed, which are intended to be measures of spectrum use effectiveness. A book on spectrum management techniques would not be complete without reference to spectrum utilization criteria. This refers to a continuous set of efforts to develop and implement a comprehensive methodology for ascertaining a means for determining the relative effectiveness with which various spectrum users make use of spectrum resources.

None of the concepts discussed below are being used in practice. However, one or another has achieved varying degrees of acceptability. The need for developing such criteria or measures has been predicated on the assumption that they would promote a basis for making judgements with regard to the appropriate amounts to be provided to different users. There is also, implicit in the development of such measures, the requirement that the electromagnetic spectrum be viewed as a resource; and is therefore, an economic factor whose value can be determined by market forces.

It is the intent of this section to describe some of these measures. These include: Situation, Autonomous and Uniform Metric, Relative Value Index (RVI), and several simplistic measures of Spectrum Utilization Efficiency. In 1968, the JTAC in its *Spectrum Engineering - A Key to Progress* indicated several concepts dealing with spectrum use, an efficiency, as descibed below.[1]

6.1.1 PODAF

PODAF - meaning Power Density exceeding a specified level over an Area within an assigned Frequency band. The purpose of this concept was to provide a simple, standard unit of spectrum space utilization based on a specified level of radiated energy density over a specified bandwidth within a specified geographical area. This concept envisions that when a spectrum user is given an assignment or license, it would have a certain number of PODAF's associated with it.

This approach would provide both a record of spectrum space assigned and the basis for calculating the degree to which all spectrum space is actually assigned in any one area.

6.1.2 Spectrum Usage Efficiency

Spectrum Usage Efficiency is a basically more sophisticated extension of the PODAF. Under this concept, spectrum utilization efficiency (s) is obtained by a combination of the volume (v), bandwidth (B), and time factors (t), for an idealized system*. It is then compared to an actual system; thereby deriving an efficiency. Such an efficiency is represented by:

$$E_s = \frac{S_i}{S_d} = \frac{V_i\, B_i\, T_i}{\sum_{i}^{n}\left[V_{dj}\, B_{dj}\, T_{dj}\right]} \qquad j = \text{no. of users}$$

The terms in this equation are:

Volume Utilization: The ideal volume, V_i, is defined as the minimum required to effect communications at a specified grade of service. The volume actually used is the volume denied, V_d, to other potential users. The volume denied is further defined as that volume within which another user cannot operate due to two factors: technical considerations and rules and regulations.

Bandwidth Utilization: The ideal bandwidth, B_i, is defined as the minimum required to effect communications with a specified modulation and grade of service. That part of the spectrum used is that bandwidth denied, B_d, other users. The denied frequency spectrum is considered to include total spectrum occupancy of the receivers and transmitters comprising a specific system. This includes spectrum occupied by such factors as sideband splatter spurious emissions, spurious responses, and intermodulation.

* The *ideal system* is defined as that system of transmitters and receivers which accomplishes a required mission with minimum use of the spectrum.

Time Utilization Efficiency: The ideal time, T_i, is defined as the minimum required to render a specific type of service. The time utilized is that denied other users, T_d.

Systems Spectrum Utilization Efficiency: Systems utilization efficiency is defined as the ratio of the product of the ideal volume, bandwidth, and time to the denied product of volume, bandwidth, and time.

6.1.3 Effective Service Sum

Under this concept, it is assumed that all operations requiring radio frequencies may be defined as services; and that each service requirement can be expressed in terms of specific time periods that the service is available or required to be available. The Service Sum is therefore the sum of the number of services multiplied by the required hours, and has the dimension of service hours, e.g.:

$$S(t_o) = \sum_{k=o}^{k=n} k\, t\, \Lambda\, \phi$$

where:
- Λ = relative utility of each service
- ϕ = likelihood each service available
- t_o = time service is available
- k = # radio services.

This concept is illustrated by the following example: In the State of Illinois, 6 MHz of VHF spectrum is used for the land mobile service. Channeling is 25 kHz per channel to provide 240 channels. Forty channels provide fire protection to 100 communities. This yields a relative utility per channel of 50, and a service probability of 0.8. The other 200 channels are used in 100 communities with 20 users per channel. The relative utility is 1 and the service probability is 0.7. The service can then be calculated as below to give 10^7 hours per day.

$$S = (40)\,(100)\,(50)\,(0.8)\,(24)$$
$$+\ (200)\,(100)\,(20)\,(1)\,(0.7)\,(24) = 1.056 \cdot 10^7 \text{ service}$$
hours per day.

For comparison with television, when normalized to a 6-MHz bandwidth, as shown:

$$\text{TV}/6\text{ MHz} = 6.048 \cdot 10^7 \div 11 = 0.55 \cdot 10^7 \text{ service}$$
hours per day.

The conclusion is reached, that with the above assumptions, land mobile

is about twice as effective in spectrum usage as VHF TV.

6.1.4 Relative Value Index (RVI)2

The above approaches are absolute measurement approaches. In contrast, the RVI was developed to (1) demonstrate the feasibility and utility of a relative measurement approach for determining spectrum value; (2) indicate the common technical, economic, and socio-political dimensions of different spectrum uses which determine value; (3) identify the parameters necessary to measure spectrum value; and (4) provide a decision model to incorporate the variables into the management process. The RVI model is:

$$RVI = (1/S)\ \frac{Y(Iu + Ip)}{C}\ PTa + \frac{1/Up \cdot Tp/T}{B}$$

where:

- PTa = average number of hours a population may be served a day.
- B = unit B of spectrum required to perform service.
- 1/Up = Urgency of Need designation.
- Tp/T = ratio of channel hours devoted to a particular purpose to the total number of channel hours service is on-the-air.
- Y/C = Economic activity ratio, where
  - C = Annual operating costs
  - Y = Annual contribution to GNP
- Iu = Spectrum user investment
- Ip = Public investment.

The spectrum manager is then to use this model in the following way:

1. The nation is divided into K spectrum/geographic regions (1 to K).

2. Each request for spectrum is for a given number of units of spectrum space in bandwidth, and crossing 1 to K regions with N units of spectrum available in each region. The total amount of spectrum to be allocated may thus be viewed as a matrix, KN, shown in Fig. 6.1, with individual requests being for blocks of this matrix. In this regard, the white cells indicate available space, not requiring any accommodation. The dark cells indicate occupied space, the reallocation of which requires effective accommodation.

3. Each request for one unit of spectrum bandwidth, crossing one to K regions, is assigned one individual RVI score.

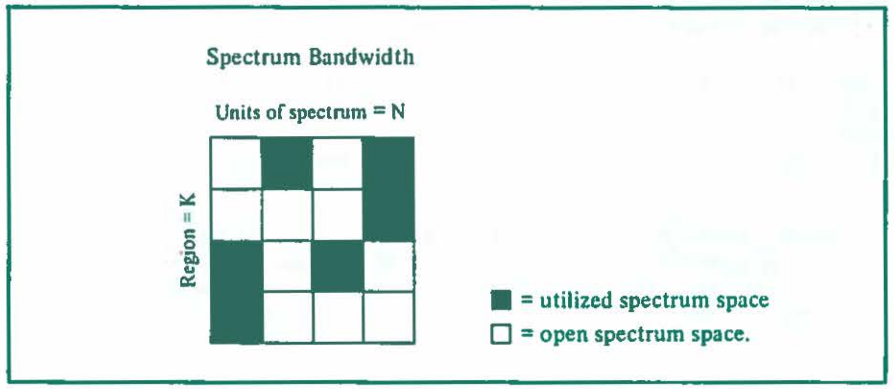


Figure 6.1 - Region/Spectrum Matrix

4. The assignment aim is to maximize the sum of RVI's subject to the constraints of spectrum availability within each individual region, and across spectrum regions.

5. The general form of the alorithm for this assignment may be restated as:

MAX - RVI, subject to the constraints:

1. Total units of spectrum assigned in each region:

$$\sum_{i=1}^{N} Rij \leq N$$

2. Total units of spectrum assigned for the nation:

$$\sum_{i=1}^{N} \sum_{i=1}^{K} Rij \leq KN$$

Placing the problem in this form allows the explicit introduction of the concept of diminishing marginal payoffs as additional units of spectrum bandwidth are assigned to the same user, which is especially relevant when these are to be used for separate purposes. Conversely, if this concept is not relevant, then the total RVI of any user's request can be divided by the number of units of bandwidth requested to give a constant RVI per unit. Even in this case, the intersection of the space constraints and the RVI may dictate a partial fulfillment of a request for multiple units of bandwidth; provided this is technically feasible. The minimum usable bandwidths, for each user in this latter regard, can be introduced as separate constraints.

6.1.5 Spectrum Metrics[3]

Each of the above measures has certain deficiencies. The PODAF oversimplifies the actual physical situation. the Effective Service Sum and the RVI deal with only efficiency and not actual quantity , and the Effective Service Sum uses service as a basic commodity. It is too difficult to define the ideal system in the Spectrum Use Efficiency.

Several recent attempts have been made to develop explicit spectrum metrics which give balanced consideration of the use of spectrum by both transmitter and receiver. These metrics attempt to incorporate realistic information about the emission and selectivity of radio systems; and yet, are easily calculable.

6.1.5.1 Situation-Specific Denial

This measure is the volume of spectrum space that a system denies actual existing systems that are competing for allocations. The result of application of such a metric are shown in Fig. 6.2 for various receivers. The combined spectrum space that a system denies to all competing systems is the measure of its spectrum space usage.

6.1.5.2 Uniform Denial

The measure can be the volume of the spectrum space denied by a transmitter (receiver) to an idealized *reference* receiver (transmitter). Once the reference is chosen, this measure depends only on the characteristics of the station being evaluated. This metric is illustrated by determining the space denied to a reference transmitter by a particular receiver, R. Assume the transmitter has an isotropic antenna ($G_T(\phi) = 1$) and a perfect narrow spectral density function, $P(f_1 f_T) = 0$; P_T = emitted power of the reference transmitter. Then:

$$P_R \text{ (the interference threshold of evaluated/receiver)} = \frac{P_T g_R(\phi)}{g(f_T;\ f_R)}\, \ell(f_T d);$$

where: $\ell(f_T, d)$ = transmission loss
ϕ = azimuth angle
$g(\phi)$ = gain of receiver antenna
$g(f,f)$ = selectivity function

This equation is applied to a system having three receivers, located at R_1, R_2, and R_3, in Fig. 6.3. Then for a particular frequency separation; the area denied by each receiver is indicated by the light lens, with overlapping prediction areas shaded.

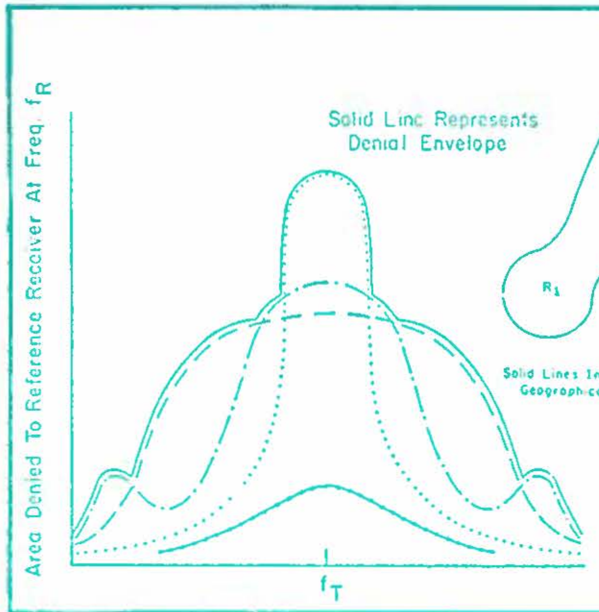


Fig. 6.2 - Measure of Composite Denial of Spectrum-Space by Transmitter T to the 4 Receiver Types

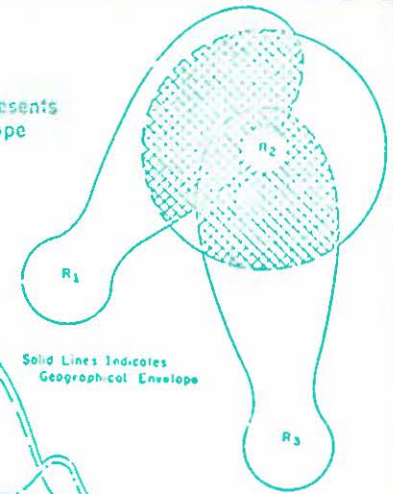


Fig. 6.3 - Overlapping Receiver Denial Areas.

6.1.5.3 Autonomous

The measure is dependent only upon the characteristics of a particular station (receiver or transmitter) which deny space to others. The most important characteristics are the emission or admission characteristics of the station, and grade of service required.

This metric is not inherently a calculation of spectrum space denied to other systems, but it is proportional to the amount of spectrum space used for the important special case of free space transmission loss and two spatial dimensions. The transmitter and receiver metrics in this case can be simplified to:

$$M_T = \tau P\ go\ ;\ M_R = \frac{\tau}{\phi\ go^1}$$

where, P = transmitter power; go is the maximum gain of the antenna,
τ = time,
ϕ = selectivity

These metrics are an attempt to provide a more realistic measure of spectrum use. However, until perfected, they are not likely to be utilized as real spectrum management tools.

6.2 COMPATIBILITY OF C-E SYSTEMS WITHIN BAND

As mentioned in the chapter on planning techniques, it is becoming increasingly important to have analytical techniques which can provide rapid macroscopic evaluation of the potential interference problems within a band. Such techniques are important in the context of both system review and band assessments.

Such band-sharing analyses are intended to provide quantitative indications of potential problems in a frequency band of concern, as well as to identify the options available to the spectrum manager for dealing with the problems.

The assessment normally proceeds in several phases. These are described in Table 6.1.

Table 6.1 - Phases of Spectrum Resource Analysis

Phase I:	Systems are identified, along with availability of technical and operational data. Potential interactions are assessed.
Phase II:	All possible system interactions are given quantitative analysis. Analyses are based on best available data. Courses of action are identified that promote compatibility.
Phase III:	Additional periodic assessments are carried out to take into account new inputs, such as new systems or design changes

The critical techniques in these analyses are (1) those which identify required distance separations between systems, and (2) those which analyse the effects of additional intersystem isolation through off-tuning (or other means) on distance separation.

Fig. 6.4 is a block diagram of a generalized band-sharing assessment analysis procedure.

The basic factors considered in generating frequency-distance relationships are shown in Fig. 6.5. The transmitter is tuned to some frequency f_T and generates a power spectrum which is a function of modulation type and equipment. A signal from the transmitter passes through the propagation path and enters the interfered-with receiver; which has certain band-pass characteristics, dependent on modulation, signal parameters, and filtering. The objective of the analysis is then to determine the amount of power in the interfered-with receiver, due to the interfering transmitter. When this is related to a threshold of user interference tolerance, decisions can be made with regard to optimum separation distances. The procedure is to determine the amount of interference protection required for a given frequency

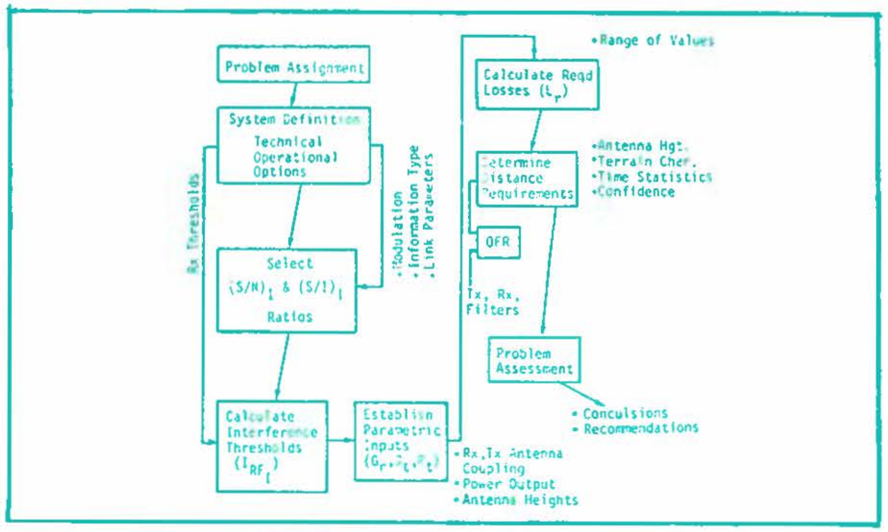


Figure 6.4 - A Generalized Band-Sharing Assessment Analysis Procedure.

separation and interference level, and then to solve the propagation calculation backwards (i.e., given loss, find distance) to determine the separation required to give protection. These analyses may be performed by using the system performance measure of I/N (interference-to-noise power ratio) at the interfered-with receiver. Fig. 6.6 shows frequency/distance curves for four values of I/N. These could represent four values of transmitter power or antenna gain.

The analysis described above are predicated on assumed discrete values of the electronic systems. In truth, the parameters of a system will vary statistically with time.

Analysis of frequency/distance relationships which may occur in a statistically-varing situation requires a comprehensive model. Fig. 6.7 indicates the functional block diagram for such a model.[4] The statistical frequency/distance curves which can be generated using such a model can provide the basis for trade-offs which apply for the full range of probabilities of occurance. Such a tool has great utility, which can be applied to problems over a broad range of conditions. For example, curves such as that in Fig. 6.8 can be generated. This figure indicates that when antennas for the interfering transmitter (TEST XMTR) and the interfered-with receiver (TEST RCVR) are physically separated by 15 nm, and the systems have tuned frequencies which are separated by 8 MHz, the interference criterion of I/N = 10 will be violated 90% of the time. On the other hand, if the tuned frequencies are separated by 9 MHz, the I/N of 10 dB will be exceeded 50% of the time. If they are 11 MHz apart, the I/N will only be greater than 10 dB for 10% of the time.

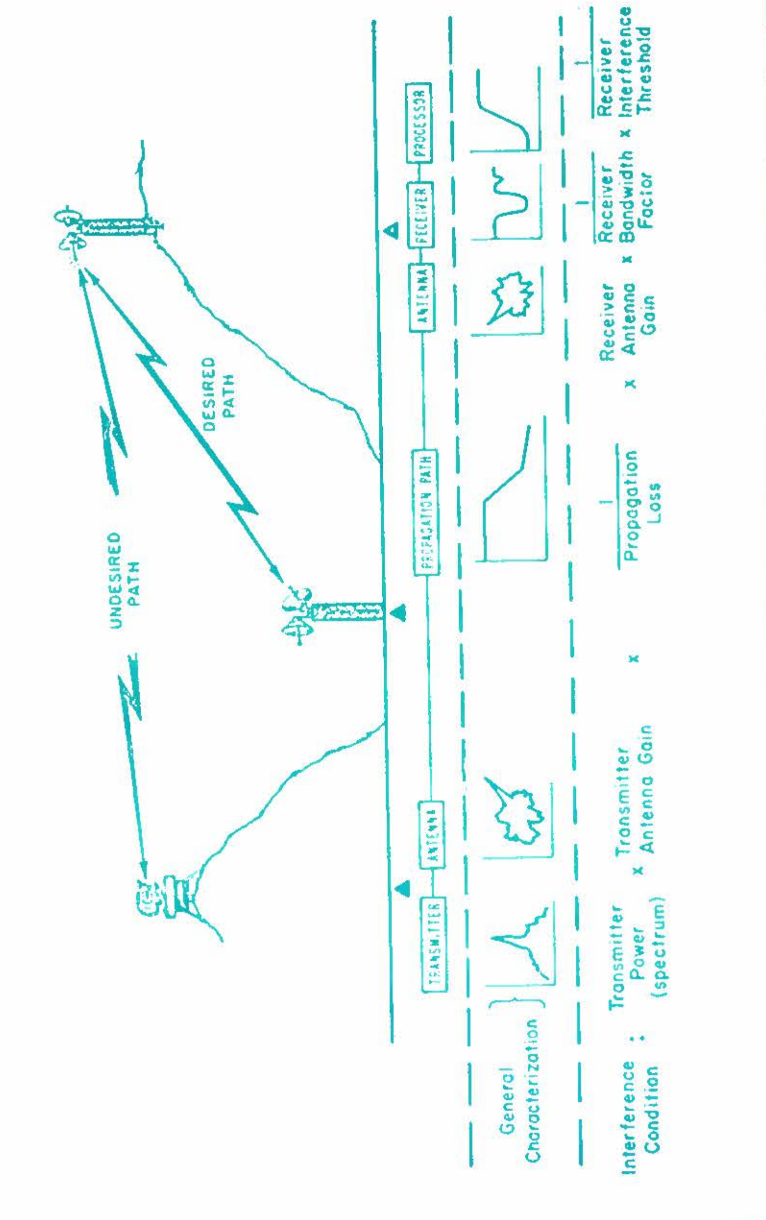


Figure 6.5 - Pictorial Representation of the Basic Factors Considered in Generating a Frequency-Distance Curve.

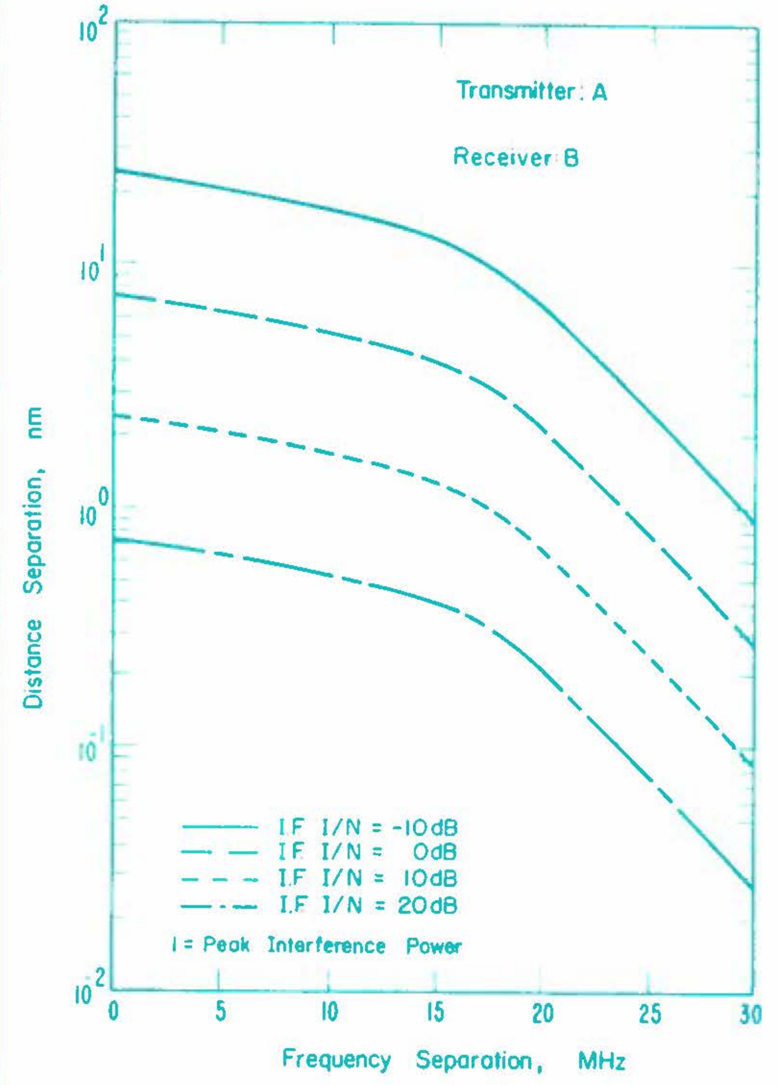


Figure 6.6 - Sample Frequency-Distance Separation Curves Generated from Discrete Data to Illustrate Parametric Treatment of the I.F.I/N Criterion.

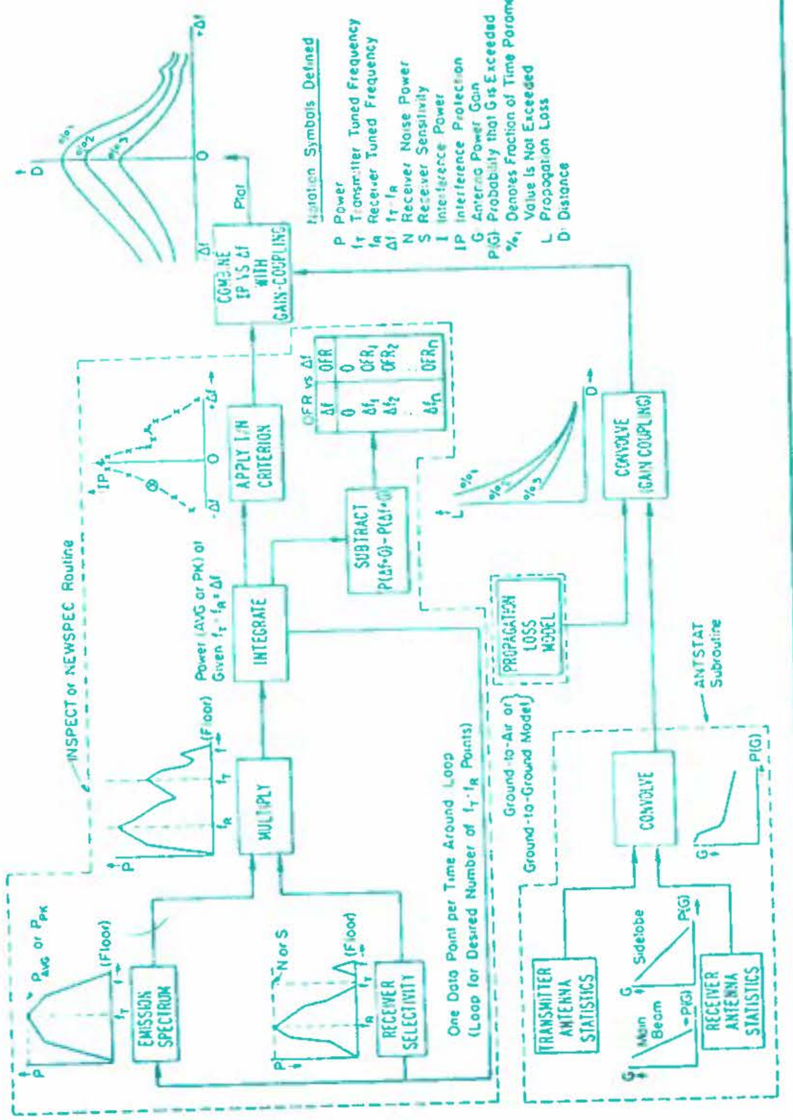


Figure 6.7 - Functional Block Diagram of the Statistical Frequency-Distance Curves Model.

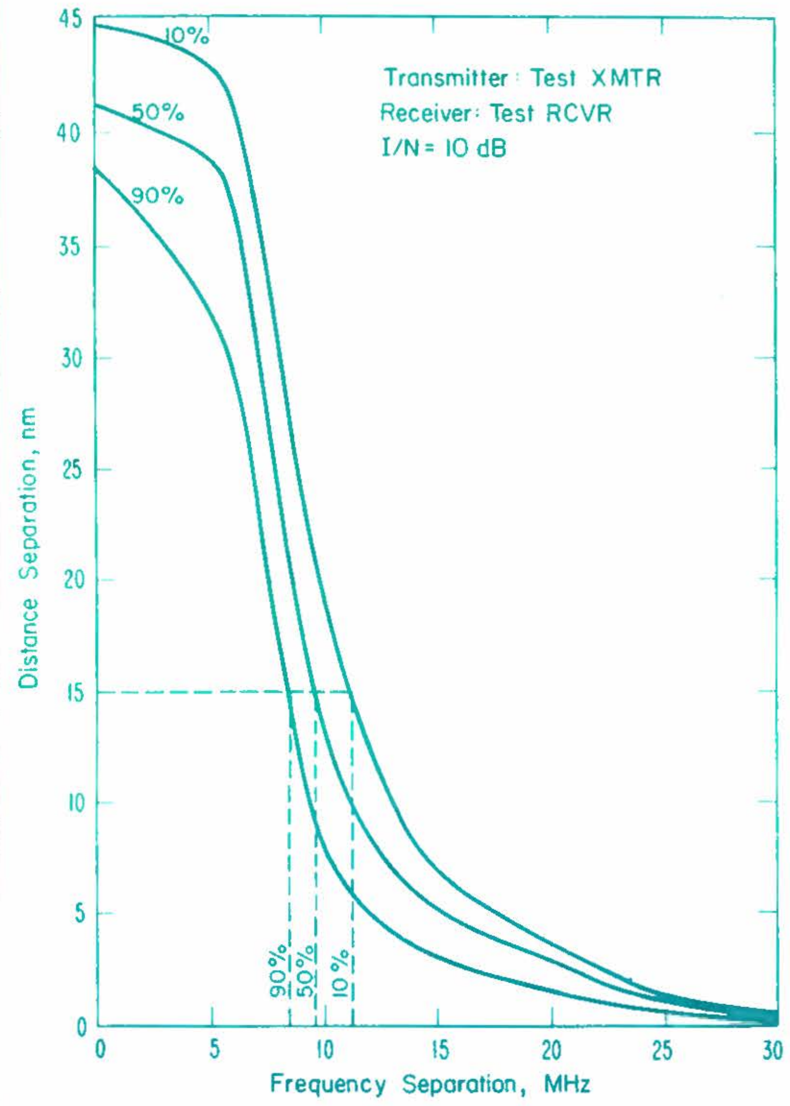


Figure 6.8 - Sample Statistical Frequency-distance Separation Curve Illustrating Application for a Specified Distance Deparation

The application of these techniques, on a systematic basis to each of the interfering situations among the systems within a particular band, provides the basis for stating whether there are serious problems, managable problems, or no problems. Furthermore, if there are problems, these analyses will point out directions of solutions.

6.3 SYSTEM-TO-SYSTEM COMPATIBILITY

This section will describe techniques for addressing compatibility between two specific C-E systems. Such techniques come into play once the procedures and analyses of the previous sections have identified interference interactions between two systems which are either serious or manageable. The techniques used to solve these situations involve a combination of detailed testing and coordination analyses.

Illustrative of the techniques which have broad applicability, are those which have been developed and utilized to solve system-to-system compatibility problems between terrestrial microwave systems operating in the same band as a satellite system; and an airborne terminal operating over wide geographical areas.[5]

The system links are symbolically illustrated in Fig. 6.9. The links involving the satellite, its earth terminal station and the terrestrial microwave stations are manageable problems. The analysis techniques used in the management include the following.

6.3.1 Earth Station Coordination Distances

In general, fixed satellites have been allocated to share bands with terrestrial microwave stations. Procedures have been developed to compute coordination distance as a function of azimuth angle relative to the earth station near beam direction. Calculations are based on a set of specified interference signal levels for each source that can be exceeded no more than a percent (normally .01%) of the time. Individual coordination curves are calculated, considering the earth station as a source, as well as the interfered-with station. Examples of coordination contours are shown in Fig. 6.10.

6.3.2 Earth Station-to-Microwave

If a microwave station lies within one of these contours, coordination must take place. This coordination must examine the predicted signal-to-interference (S:I) ratios and compare them to those required for satisfactory performance. Predicted S/I ratios may be given by:

$$S/I = S/N - (P_t + G_o - L_f - \Delta f - R_s)$$

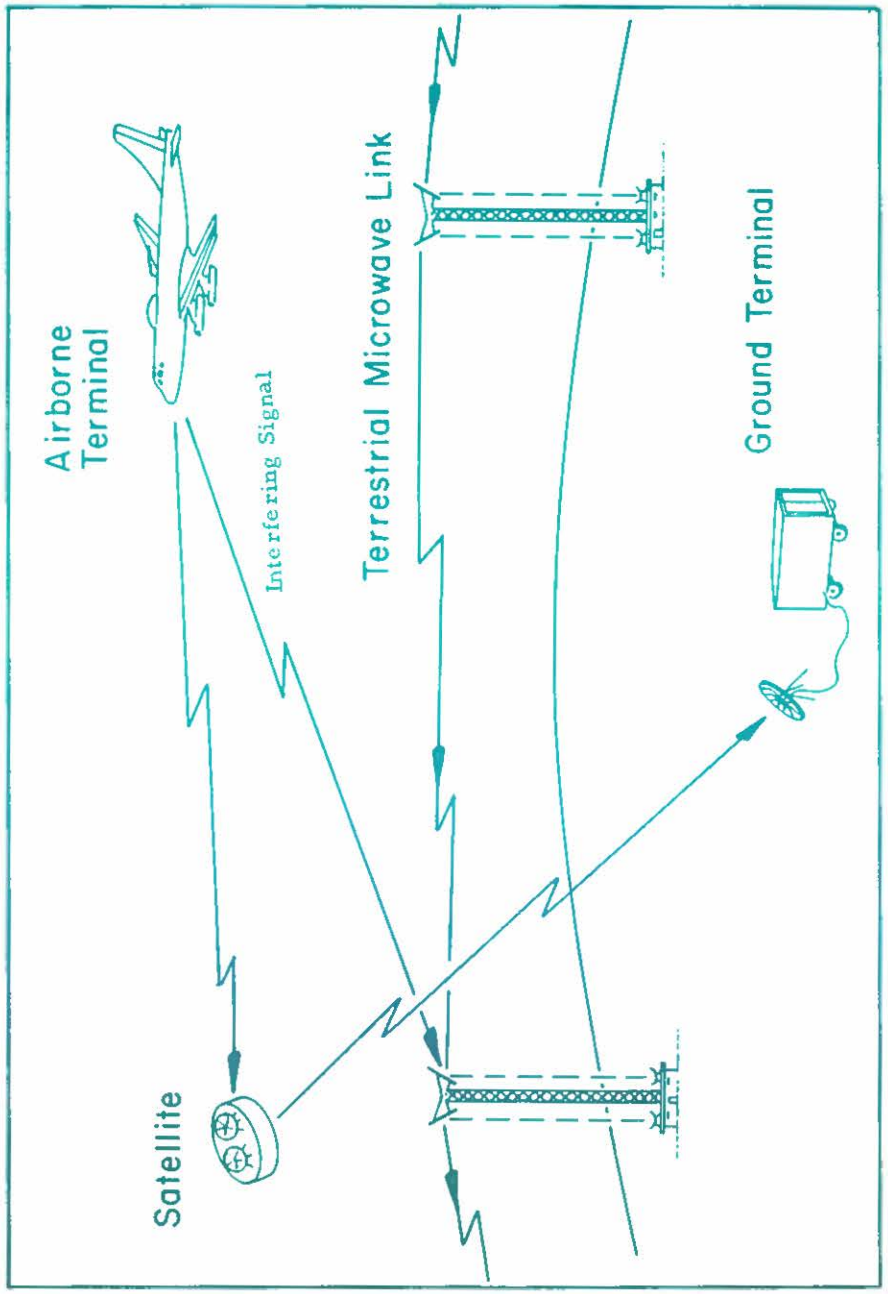


Figure 6.9 - Interference to Microwave Link from Airborne Satellite Terminal

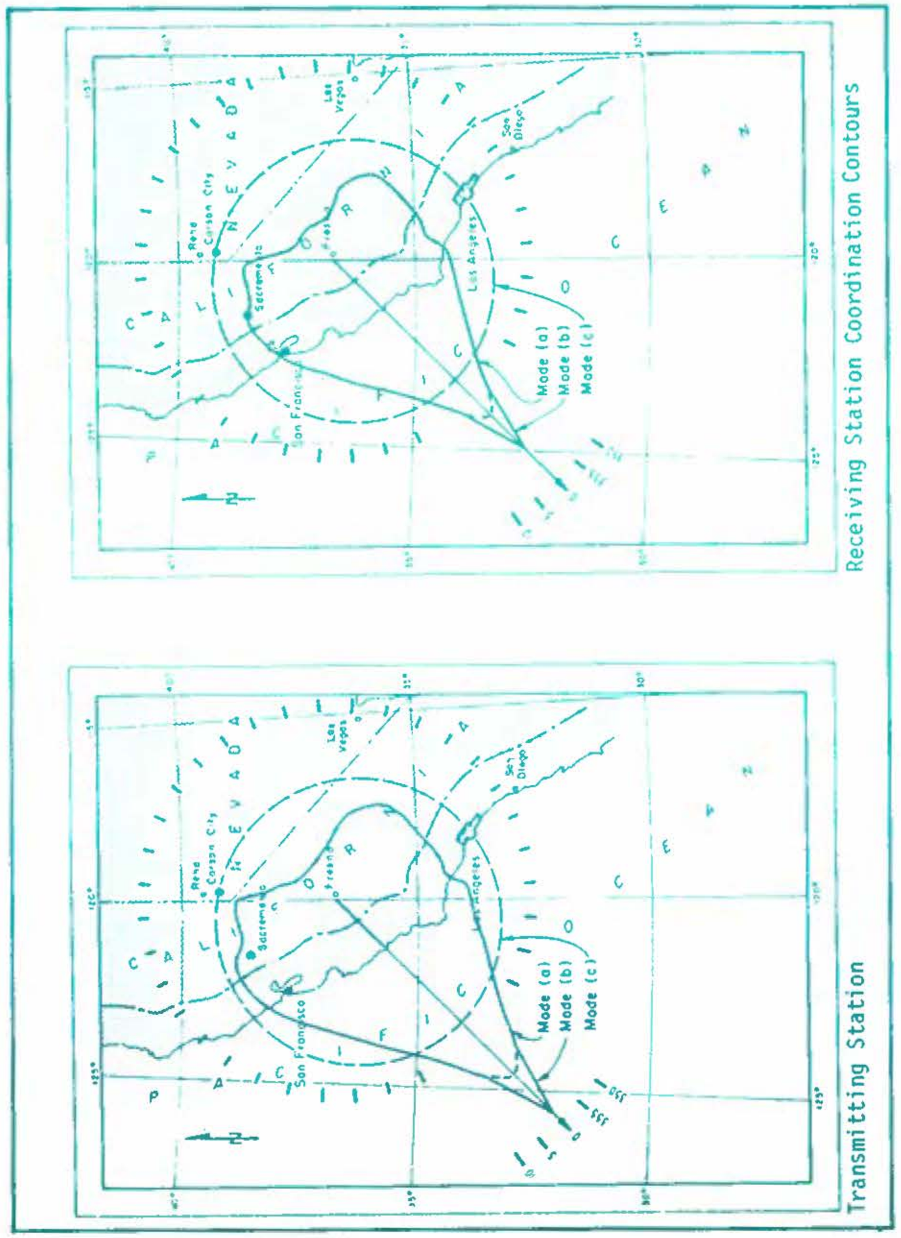


Figure 6.10 - Earth Station Coordination Contours.

where, S/N = design input signal-to-noise, dB

P_t = transmitter interference power

G_o = antenna coupling

L_f = path loss

Δf = off-frequency system

R_s = receiver sensitivity

G(o), the antenna coupling, may be analyzed as illustrated in Fig. 6.11 for the two dimensional case. It is considered the cumulative angular isolation, $\delta\theta = \theta_1 + \theta_2$. Additional techniques are used to select performance values, for these, combined with the above, give the predicted S/I's.

6.3.3 Satellite Link Interference

When the combined characteristics of satellite antenna pattern and gain, and power are factors in an interference calculation, the technique of plotting satellite *footprints* may be utilized. Such a footprint is shown in Fig. 6.12. The contours in this figure are plots of power flux density on the earth's surface. These contours are constructed by searching outward along rays emanating from the maximum power point for the desired signal level and its corresponding location.

This specific serious problem involved the mobile airborne terminal, and the terrestrial microwave stations. In such a case, tests were required to ascertain the nature of interference. The rationale and methodology for carrying out such tests is indicated in Fig. 6.13. The specific problem was the interference created by the back lobe and the side lobe radiation patterns of the airborne terminal.

The tests revealed that unacceptable interference would take place under certain circumstances at certain locations. A technique which can be utilized to avoid these locations is illustrated in Fig. 6.14. This figure consists of interference contours which indicate those regions where levels from an interference source would exceed specified thresholds at the receiver. These thresholds are specified in terms of signal-to-interference ratios, which are directly related to performance. The contours have been developed by a computer program which considers the geometric relationship between an elevated signal source and specific points on the earth's surface.

More and more, techniques such as those detailed above are being developed to handle system-to-system interference situations. The references at the end of this chapter are sources of additional information on this subject.

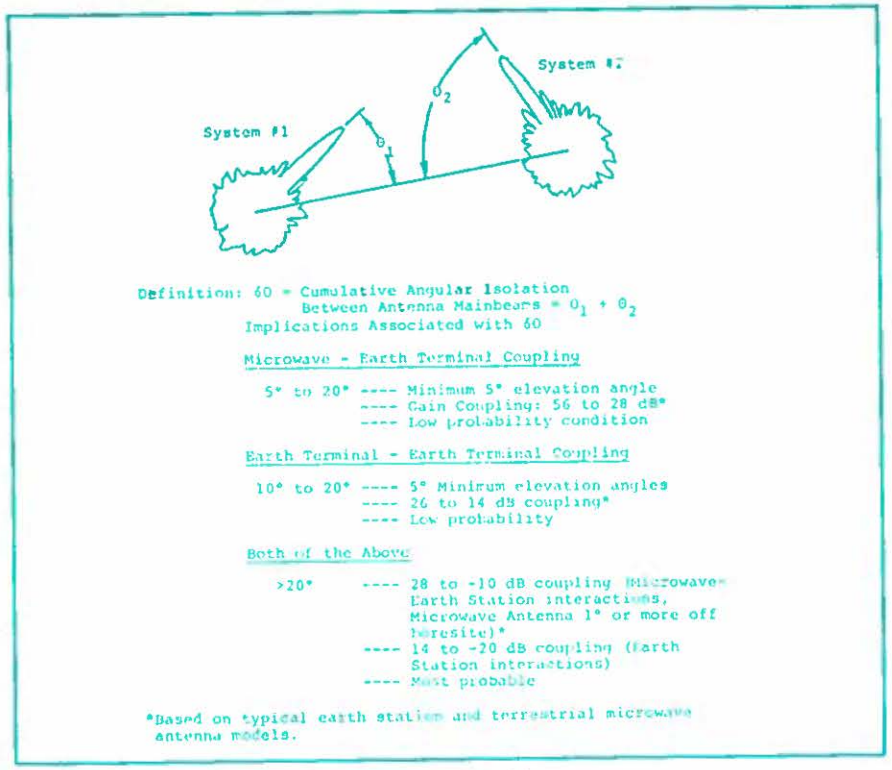


Figure 6.11 - Antenna Coupling Relationships

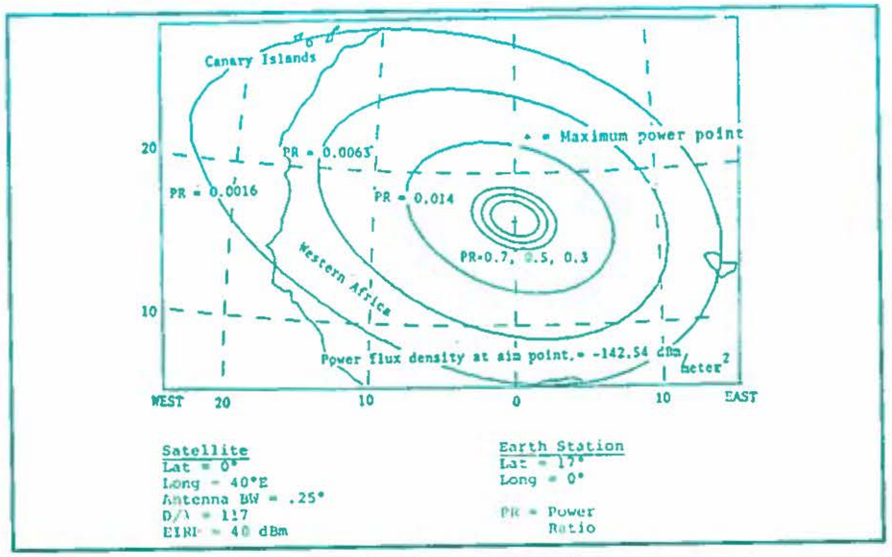


Figure 6.12 - Representative Satellite Footprint

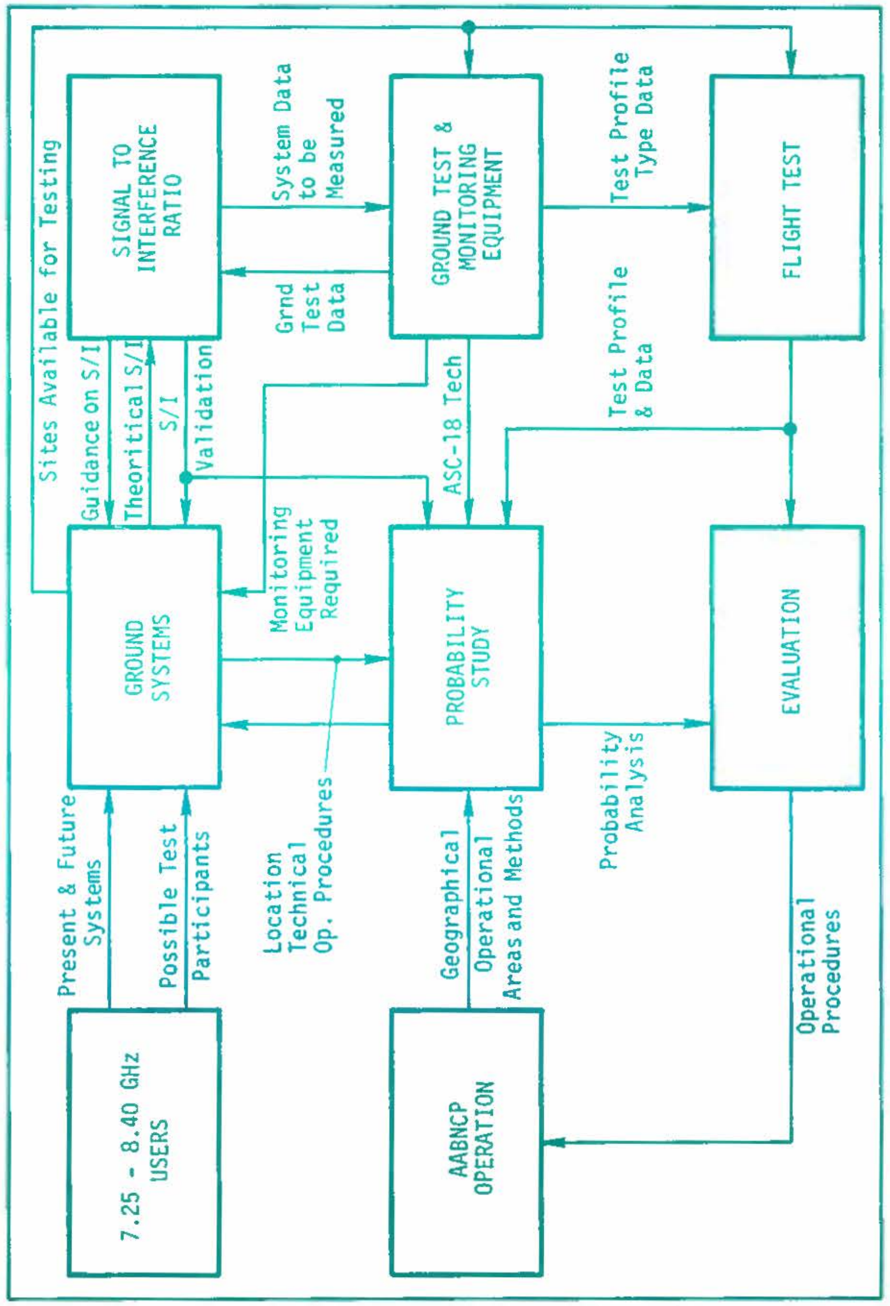


Figure 6.13 - Block Diagram for Interference Tests

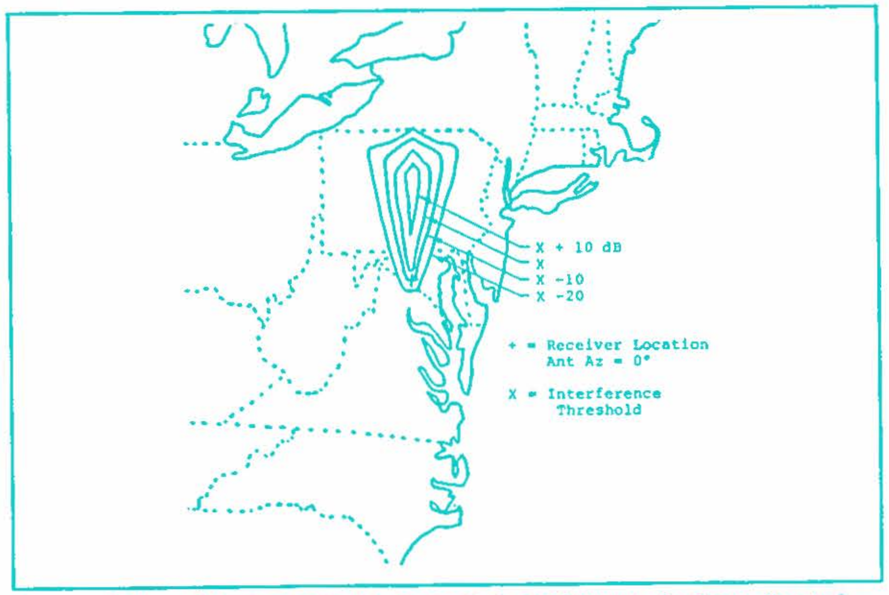


Figure 6.14 - Illustrative Co-Channel Interference Regions About A Terrestrial Receiving System.

6.4 PROBABILISTIC APPROACHES TO COMPATIBILITY ANALYSIS [6]

Previous sections have described techniques presently in use and being developed, which can be used to ascertain whether a particular communication-electronic system will be able to perform its intended function in the particular EM environment in which it finds itself. However, these techniques are all based on assumptions, which lead to conservative engineering judgements. These, in turn, determine how close two or more systems may be configured without unacceptable interference to each other.

There does not exist a general theory for the performance of telecommunication systems in the spectral-use environment. This situation is characterized by a number of deficiencies:

1. Lack of availability: Pertinent data are scattered under various types and classifications, etc.

2. Lack of standardization: Experimental and theoretical results obtained under a variety of more-or-less limited and incomplete criteria of measurement and performance.

3. Limitations on reliability: i.e., on the *quality* of the data: inadequate "ground truth" for adequate assessment of

performance. (e.g., missing environmental factors, inadequate modeling, and interpretation);

4. Limitations on applicability: for example, S/N criteria vs the more realistic error probability measures; optimality vs sub-optimality criteria for actual use; and lack of adequate environmental models;

5. Limitations on predictability: This is a consequence of 1 - through 4 above. Also, it is the result of the inadequacy of many current EM environmental models and predictions made therefrom;

6. Lack of decision costing and evaluation: Performance evaluations need to include the "costs" of decisions stemming from the communication process. These also are part of the more realistic criteria required for assessment, cf. 4 above.

7. Limitations on technical scope: While the single-link system (transmitter - EM environment - receiver) in the interference environment is necessarily the fundamental unit for study; the analysis techniques appropriate here need to be extended to multiple-link and inter-system structures, with particular emphasis on communication trade-offs and efficiencies, costs, and pay-offs, etc.

Attempts are presently being made to rectify these deficiencies.

Such a general theory of telecommunications systems performance would permit the determination of the characteristics of electronic communication systems of all types and applications in both actual and potential interference environments. To accomplish this will require the development of procedures, analyses, and concepts by which the necessary data base may be established and by which deficiencies of current approaches may be mitigated.

The functional relationship of the theoretical analysis to the end-product performance predictions is shown in Fig. 6.15. The physical parameters are well known.

A first step in the development of the general theory is definition of models of the EM environment. The various environmental factors are interralated in the manner illustrated in Fig. 6.16, where:

where, (a) = Single link in EM environment

(i) other intelligent links
(ii) unintelligent EM interference fields

(b) = $\sum_{i=1}^{N} T_i(R)$ multiple links incorporated as a system in an EM environment.

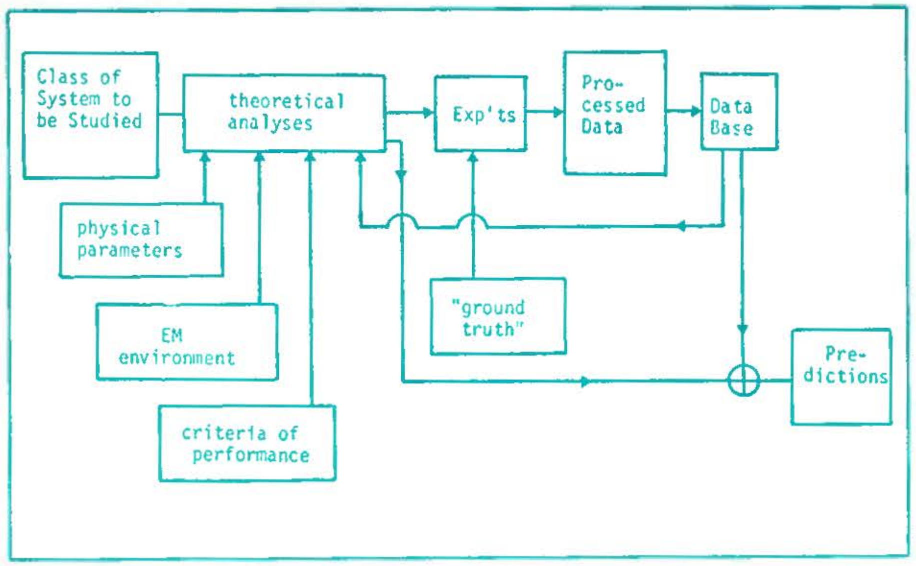


Figure 6.15 - Relation of Theoretical Analyses to End-Product: Performance Predictions

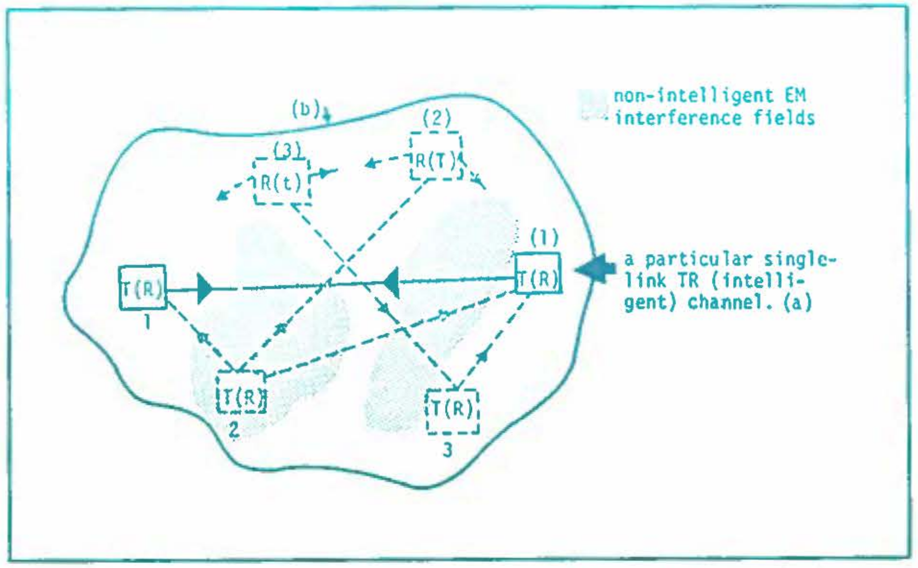


Figure 6.16 - Schematic of EM Environment; (a) and (b), above.

(i) other intelligent systems
(ii) unintelligent EM fields.

Models of the EM environment are required to indicate the relevant parameters, and to show how they appear in the underlying physics of the situation. Models also tell what parameters to measure, and how significant they are as environmental descriptors. Models of the EM environment are necesary for the analysis of system performance (which are a critical part of the general data base). They are related to the basic environment parameters; e.g., the error probabilities which are used as performance measures and predictors are themselves explicit (and implicit) functions of the environment models and have been classified for EM interference as follows:

<u>Class A Interference:</u> This noise is typically narrower in spectral width than the receiver in question, and, as such, generates ignorable transient decay in the receiver's front-end (e.g., aperture-RF-IF) stages when a source emission terminates.

<u>Class B Interference:</u> Here the bandwidth of the input noise is larger than that of the receiver's front-end stages; so that transient effects, both in build-up and decay, predominate. The receiver is, to varying extents, "shock-excited"; typically for inputs of short duration.

<u>Class C Interference:</u> This is the sum of Class A and Class B interferences, which can occur either because of the presence of sources of mixed types (Class A, Class B emissions), and/or because any received emission is itself strictly Class C; i.e., there is always a build-up period and a decay transient period in any front-end receiver reaction to an input emission.

Fig. 6.17 shows typical waveforms (of the envelope) at the output of the (linear) stages of a receiver for the different classes.

The above-defined categories for interference, <u>as it impacts on a typical (narrow-band) receiver,</u> (i.e., alternatively, as the receiver responds in an EM environment), provide a useful way of describing the different types of interference and their effects on reception. The method of classification may be extended further to distinguish between man-made and natural interference, and between "intelligent" and "non-intelligent" emissions. Thus:

(i) <u>*Intelligent* noise or interference</u> is man-made and intended to convey a message of some sort;

(ii) <u>*Nonintelligent* noise or interference</u> may be due to natural phenomena (e.g., atomospheric noise), or may be man-made, but conveying no intended communications; (e.g., automobile ignition noise).

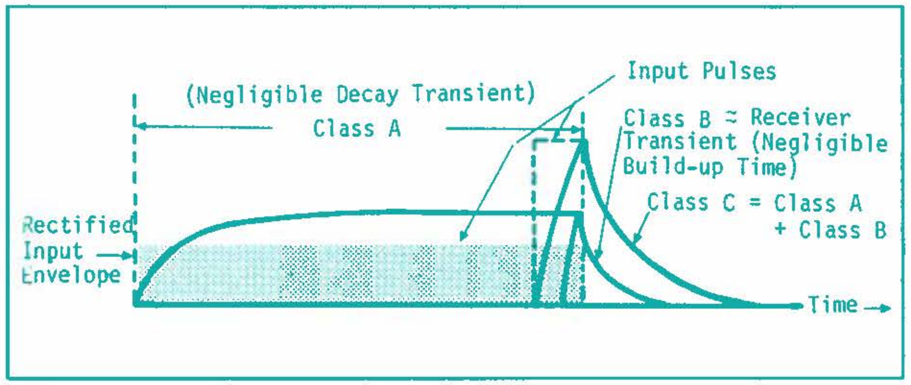


Figure 6.17 - Some typical Class A, B, & C Interference Waveforms at output of receiver (aperture x RF x IF) stages.

This section has presented excerpts of efforts presently underway which will lead to a completely generalized set of techniques for predicting the performance of communication-electronic systems in an electromagnetic environment. The development of such techniques should ultimately lead to an enhanced capability to effectively manage the radio spectrum.

6.5 REFERENCES

1. JTAC 6.31 - "Spectrum Engineering - A Key to Progress"; IEEE, 1967.

2. "Relative Value Index, Concept of Spectrum Management"; H. Bernstein; OTP, 1971.

3. "Metrics for Spectrum - Space Usage"; Berry Euing; OT/ITS Department of Commerce, 1973.

4. "Statistical Frequency - Distance Curves"; Jennings, Volger, and Stephenson, OT/ITS, Department of Commerce; 1975.

5. "Spectrum Resource Analysis - Space and Terrestrial System Band-Sharing"; R.D. Parlow, OT, Department of Commerce; 1974.

6. "Performance of Telecommunication Systems in the Spectural Use Environment"; David Middleton, OTP Research Paper; June 1975.

APPENDIX 1

TABLE OF CONTENTS
ITU Radio Regulations

INDEX

Page No.

A

B

C

D

E

F

G

I

I (Cont'd)

M

N

O

O (Cont'd)

R (Cont'd)

S (Cont'd)

T

U

W